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CHARACTERISTICS OF SMALL GRID-CONTROLLED HOT-CATHODE MERCURY ARCS OR THYRATRONS.

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ABSTRACT.

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The principle of the grid-controlled arc or thyratron is briefly described and the nominal ratings as regards filament current, maximum plate current etc. of four important thyratrons are given in table form. Methods of measuring the grid current, critical grid potential, etc., with D.C. power supply are given along with the results obtained on the General Electric Company thyratrons *FG*-17, *FG*-27 and *FG*-67. Characteristics obtained with A.C. power supply are also shown for these thyratrons and some of the relative advantages of the "phase-shift" and the "critical potential" methods of control are discussed when used in connection with photoelectric cell circuits. The A.C. measurements seem to show that a time of 10^{-3} second is required to start a thyratron. An amplifier circuit is shown by which it is theoretically possible to control a thyratron circuit using an input current to the amplifier of 10^{-11} ampere.

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INTRODUCTION.

The name "Hot-cathode thyratron" has been given by Dr. A. W. Hull[1] to the grid controlled hot-cathode mercury arc which has recently been developed by the General Electric Company. The mechanical features and some of the electrical characteristics have been described by Hull and Langmuir,[1, 2] but many details of importance have not been published. In particular the fact that a grid current flows in the grid circuit before the discharge begins has not been emphasized. In fact it is sometimes said that the "thyratron is an electrostatically controlled arc rectifier." In a very large number of engineering applications, it is of no importance that *power* must be furnished to the grid from the control circuit, but in many problems in the physics laboratory it is important to know that power is required in the grid circuit even though it is as small as a micro-watt. This paper is therefore addressed to physicists and engineers who must interest themselves in the *detailed mechanism* of the thyratron in order to use this new and valuable thermionic device to the best advantage. It will be obvious to the reader that the experiments described here open up almost as many questions as they answer. Further experiments using the cathode-ray oscillograph, a variable frequency generator etc., may show that the interpretations of some results are not correct in every detail, but since it is not possible to carry out these more crucial tests in the near future, the results to date are being presented with the belief that they are of sufficient value to warrant their publication.

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[1] *Gen. Elect. Rev.*, **32**, 213 and 390 (1929).

[2] *Proc. Nat. Acad. Sci.*, **15**, 218 (1929).

THE PRINCIPLE OF THE GRID CONTROLLED ARC.

The "thyratron" is a tube quite similar to the ordinary three element vacuum tube. There is a hot cathode to emit electrons, a plate to collect them and a grid between the cathode and the plate to control the flow of the electrons across the space. After evacuation, mercury which has a vapor pressure of 6×10^{-3} mm. at 40° C. is introduced as the "inert" gas * in the tubes described here. *Before the arc starts*, the grid current and plate current characteristics as a function of grid potential are identical in form with those of a gassy "vacuum" tube.[3] As the grid potential is made less and less negative, the plate current increases until, when it is about 0.2 micro-ampere, the rate of production of ions is so great that a positive ion sheath [4] is formed around the grid, neutralizing the negative charge maintained there by the bias battery. The grid then loses control and the arc starts. After the starting of the arc, the current flowing between the cathode and the plate is limited only by the external circuit conditions, assuming that the normal electron emission current from the cathode is not exceeded. The grid no longer has any appreciable control and the arc can be stopped only by lowering the plate potential below the ionization potential of the gas for a time long enough for the ions to become neutralized. When the plate potential is furnished from an alternating current source, the grid regains control during each negative half of the cycle if the frequency is not too high.

PRESENT RATINGS ON CERTAIN GENERAL ELECTRIC CO. THYRATRONS.

The characteristics which are shown in this paper must not be taken as average characteristics in any sense because only two to four samples of each type have been measured and because the manufacturing changes from time to time cause considerable alteration in such a commercial product.

In order to assist the reader in comparing the rated characteristics of the small thyratrons, Table I has been prepared from the technical information issued by the "Vacuum Tube Engineering Department" at Schenectady.

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[3] Nottingham, JOURNAL OF FRANK. INST., **209**, 287 (1930). See pages 291 and 295.

[4] Langmuir and Mott-Smith, "The Theory of Collectors in Gas Discharges," *Gen. Elect. Rev.*, **27**, 449, 538, 616, 762, 810 (1924). *Phy. Rev.*, **28**, 727 (1926).

* Thyratrons have also been made using helium, neon or argon. The characteristics of these tubes are much more independent of temperature changes.

TABLE I.

Technical Information on Thyratrons.

Code number	*FG*-17	*FG*-27	*FG*-37	*FG*-67
Manufacturer	G. E.	G. E.	G.E.	G. E.
Designed as	Controlled Rectifier		Inverter	
Cathode				
Volts	2.5	5.0	115*	5.0
Amperes	5.0	6.0	0.2	4.5
Type	Coated filament	Indirect heat	Indirect heat	Indirect heat
Fil. heating time (min.)	0.5	5.0	5.0	5.0
Max. peak volts on plate	2500	1000	1000	1000
Max. plate current				
Instantaneous	2.0	10.0	15.0	15.0
Average	0.5	2.5	2.5	2.5
Max. tube voltage drop	24	24	24	24
Min. tube voltage drop	10	10	10	10
Temp. limits Ambient ° C.	20–50	0–50	20–50	20–50
Type of cooling	Air	Air	Air	Air
Deionization time (micro-sec.)	1000	1000	100	100
Max. freq. as rectifier	500	500	5000	5000
Gas	Mercury vapor		Mercury vapor	
			Technical information	
Published information	GET-193*B* GEJ-278	GET-195	*FG*-37	*FG*-67 GEJ-277

* 115 volts D.C. preferred although A.C. can be used.

Thyratrons are divided into two general classes called respectively "controlled rectifier" and "inverter." These differ from each other in certain details of construction, designed to produce the most efficient operation in applications for which they are intended. The controlled rectifier is the tube which is usually used in connection with low frequency alternating plate potentials while the inverter is usually used in direct current circuits when a pulsating flow of current under the control of a subsidiary device is needed.

The three types of tubes which have been tested are the *FG*-17; *FG*-27 and *FG*-67.

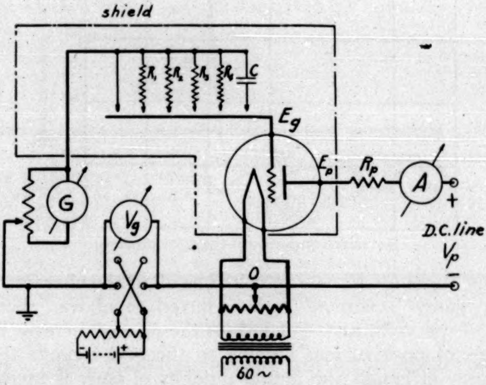
CHARACTERISTICS OF AN FG-17 THYRATRON AND METHODS OF MEASUREMENT.

The alternating current or *dynamic* characteristics of thyratrons are of greater practical interest than the *static* characteristics taken with D.C. potentials applied to the plate and the grid. The static characteristics however are of considerable theoretical interest because they can be understood in detail and they give some insight into the more complex dynamic characteristics.

(a) Static Characteristics of an FG-17 Thyratron.

The essential circuit used for the study of the static characteristics is shown in Fig. 1.

FIG. 1.



Circuit for the measurement of static characteristics of thyratrons.

In order to eliminate any possible confusion the usual conventions of vacuum tube practice will be followed.

1. All potentials are measured from the "cathode return" designated by "0" as zero.

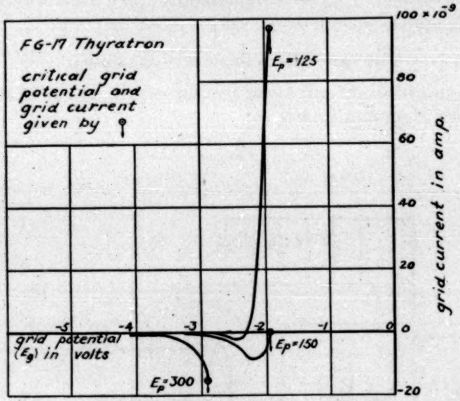
2. The positive direction of current is that of a positive charge flowing around the circuit in the direction of the applied potential. Under this convention the flow of electrons from the filament to the plate constitutes a *positive* current.

3. The "*C*" battery or grid bias potential will be designated by V_g and the actual grid potential by E_g.

4. V_p will be used for the line potential and E_p the actual plate potential.

Figure 2 shows the grid current as a function of grid potential before the discharge begins for three different plate potentials.

FIG. 2.



Grid current characteristic of an FG-17 thyratron.

The curve for $E_p = 125$ volts has all of the characteristics of the gassy "vacuum" tube referred to above. Between $E_g = -3.0$ volts and -2.4 volts the rate of increase in the number of positive ions coming to the grid exceeds that of electrons, although the actual number of each is increasing very rapidly as the grid is made less negative. Between -2.3 volts and the critical potential, the number of electrons arriving at the grid exceeds the positive ions. Since the positive ions move so much more slowly than the electrons, on account of their greater mass, a space charge is built up around the grid by this increasing number of ions coming toward it until at $E_g = -1.93$ volts an ion sheath forms around the grid; it loses control and the arc begins. With $E_p = 150$ volts the same cycle is partially completed and with $E_p = 300$ only the first stage can be observed.

An experimental difficulty in measuring these characteristics comes in on account of the fact that the current may change suddenly about a million fold as the grid potential passes through the critical value. This can be overcome by using the following procedure.

With the galvanometer shunted the critical grid potential can be determined quite accurately since it is reproducible to within about 0.02 volt over short periods of time. With the galvanometer in the circuit the grid current can be measured safely with potentials up to within 0.1 volt of the critical value. The current at the critical grid potential can be determined by a "resistance method," that is, the critical *bias* potential V_g is determined with and without a resistance in the grid circuit. If the resistance is not too high, the grid current at the critical potential is given by equation (1),

$$\frac{V_{gr} - V_{go}}{R_g} = i_g. \tag{1}$$

Here V_{gr} and V_{go} are the critical bias potentials with and without a grid resistance respectively, and R_g is the value of the resistance.

The "grid impedance" (Z_g) can be defined by equation (2):

$$\frac{\partial i_g}{\partial E_g} \equiv \frac{1}{Z_g}, \tag{2}$$

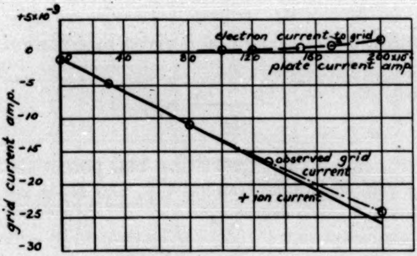
where $\frac{\partial i_g}{\partial E_g}$ is the slope of the grid current characteristic with constant plate potential, at any particular value of grid potential.

The grid impedance (Z_g) has the dimensions of a resistance and can take on *positive* or *negative* values as in the case of the 125 volt characteristic of Fig. 2. Here it is positive at the critical value of E_g. In this case the value of i_g given by equation (1) will be independent of the value of R_g but since the grid impedance is *negative* at the critical grid potential in the 300 volt characteristic, the measured grid current using equation (1) will not be the true grid current at the critical potential unless R_g is *smaller* in magnitude than Z_g at the critical grid potential.

When R_g is greater than 10^6 ohms, it is necessary to connect a capacity of about 0.03 microfarad in parallel with the resistance in order to shunt out the induced 60 cycle variations produced by the A.C. potential drop over the filament.

The negative part of the grid current characteristic was attributed above to the flow of positive ions to the grid. In order to test this assumption the plate current and the grid current were measured simultaneously as a function of the grid potential before the discharge began. The results are shown by the curve "observed grid current" of Fig. 3. The electron current to the grid was observed with the plate potential zero. The positive ion current was found by correcting the observed current for the electron current and the result is shown by the straight line "ion current" of Fig. 3. Since the opening between the grid wires is small compared with the distance between the electrodes, the assumption is justified that the electron current to the grid is practically independent of the plate potential.

FIG. 3.

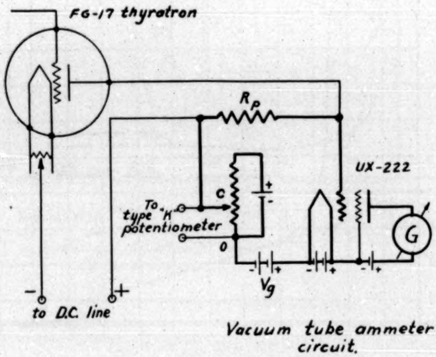


FG-17 thyratron with E_p = 200 volts. Positive ion current to grid is a linear function of electron current to plate.

This result is consistent with the theory that a small number of electrons pass through the holes of the grid, and are accelerated in the high field between the grid and the plate. Ions are produced as a result of the impact of these high speed electrons with mercury atoms. The electrons continue to the plate and the positive ions are attracted to the grid.

A galvanometer was used to measure the plate current as the grid potential was changed for grid potentials to within 0.2 volt of the critical value. The "vacuum tube ammeter" shown in Fig. 4 was used for the remainder of the range. With the contact "*C*" at "o" the bias battery V_g was adjusted to give approximately full scale deflection on the galvanometer when no current was flowing through the resistance R_p in the plate circuit of the thyratron. When a current was flowing in the thyratron, the galvanometer current measured by "*G*" decreased, but by adjusting the contact "*C*" along the resistance, the potential difference between the grid and the filament could be returned to the original value V_g as indicated by the return of the galvanometer coil to its original deflection. The potential between "*C*" and "o" divided by the resistance R_p was equal to the plate current. By this method the plate current could be measured safely right up to the critical point because after the discharge began, the large potential drop over R_p simply set up a retarding potential between the grid and the filament and the current through the galvanometer fell to zero.

FIG. 4.

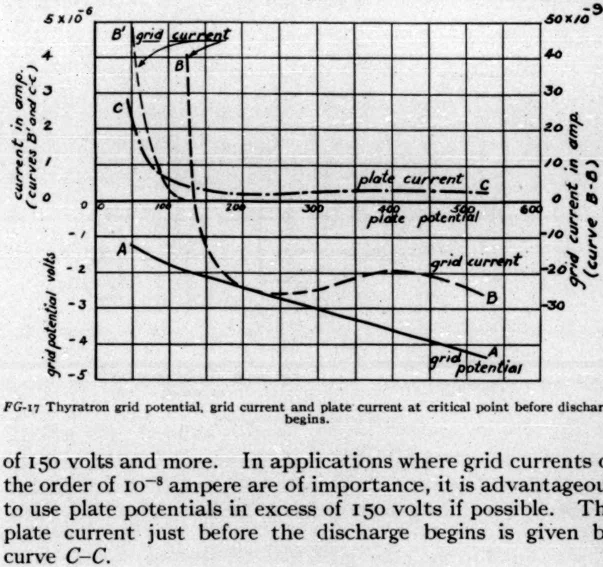


Vacuum tube ammeter circuit.

With these methods the plate current, the grid current and the grid potential were measured at the critical point as a function of plate potential. The results are shown by the curves of Fig. 5.

Curve *A* shows that the critical grid potential is nearly a linear function of the plate potential. From curves *B'* and *B–B* we see that the grid current is large and positive for values of plate potential less than 125 volts, but is negative and more or less independent of the plate potential for values of 150 volts and more. In applications where grid currents of the order of 10^{-8} ampere are of importance, it is advantageous to use plate potentials in excess of 150 volts if possible. The plate current just before the discharge begins is given by curve *C–C*.

FIG. 5.



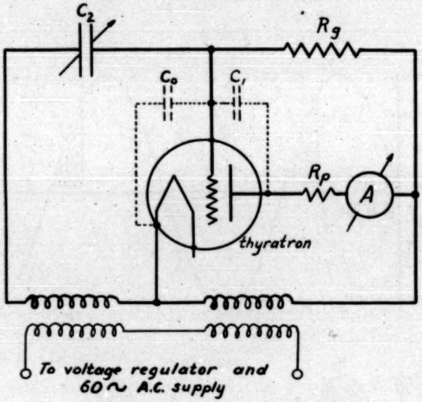
FG-17 Thyratron grid potential, grid current and plate current at critical point before discharge begins.

(b) Dynamic Characteristics of an FG-17 Thyratron.

The circuit used for the study of the dynamic characteristics of thyratrons is shown in Fig. 6.

The grid to filament and the grid to plate capacities are shown in schematic form by C_0 and C_1 respectively. The values of these for the *FG*-17 thyratrons studied were $C_0 = 10 \times 10^{-6}$ microfarad and $C_1 = 2.0 \times 10^{-6}$ microfarad. When R_g is less than 10^6 ohms and the frequency 60 cycles, these capacities can be neglected and, assuming no grid current the instantaneous grid potential is given by equation (3).

FIG. 6.



Circuit for A.C. characteristics of thyratrons.

$$E_g = V_{\max} \sin (\omega t - \alpha), \tag{3}$$

where

$$\alpha = 2 \tan^{-1} \omega C_2 R_g. \tag{4}$$

The line potential V_p is given by

$$V_p = V_{\max} \sin \omega t. \tag{5}$$

This is also equal to the plate potential E_p *before the discharge begins* but after the discharge begins the plate potential E_p is approximately constant as long as the current is flowing. Graphically these equations can be represented by the curves of case *A* and case *B* of Fig. 7 corresponding to two values of C_2.

For case *A*, $\omega C_2 R_g$ is 2.0 while for case *B* it is 0.5. The cross-hatched area is proportional to the current which flows in the plate circuit during each cycle, according to this approximate theory. The instantaneous potential (E_L) across the load resistance after the discharge begins is given by equation (6),

$$E_L = V_{\max} \sin \omega t - E'_p. \tag{6}$$

FIG. 7.

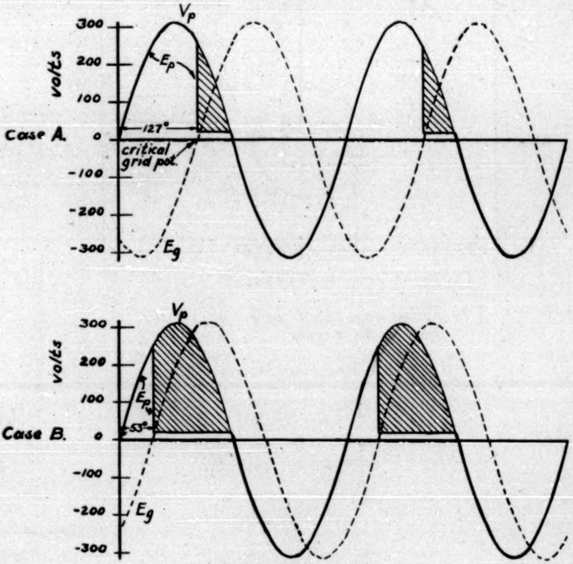


Illustration of "phase shift" method of control. Case A; $\omega C_2 R_g = 2$, and case B; $\omega C_2 R_g = 0.5$.

Where 0.707 $V_{\max}$ is the line potential as read on an A.C. voltmeter and E_p' is the potential drop over the thyratron after the discharge begins. This is seldom more than 20 volts.

The instantaneous current is given by

$$i_L = \frac{E_L}{R_p}, \tag{7}$$

and the current as read on a direct current meter is

$$I_L = \frac{1}{2\pi}\int_{\omega t = \theta}^{\omega t = \theta_0} \frac{V_{\max} \sin \omega - E_p'}{R_p}\, d\omega t. \tag{8}$$

The upper limit of integration is obtained by putting $E_L = 0$ in equation (6) and is given by

$$\theta_0 = \pi - \sin^{-1} \frac{E_p'}{V_{\max}}. \tag{9}$$

When integrated equation (8) becomes

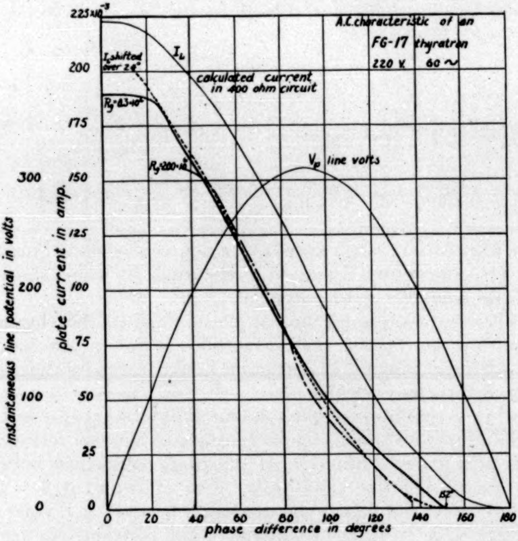
$$I_L = \frac{1}{2\pi R_p}\left\{ V_{\max} (\cos \theta - \cos \theta_0) - \frac{E_p'}{57.3} (\theta_0 - \theta) \right\}, \tag{10}$$

where θ and θ_0 are now expressed in degrees instead of radians. Here θ is approximately equal to the angle by which the plate potential *leads* the grid potential.

This very simple picture of the control of the thyratron current by the "phase shift" method, is not in exact agreement with experiment. This point is illustrated by the curves of Fig. 8 for 220 volts A.C.

In Fig. 8 the light weight solid lines V_p and I_L represent the calculated instantaneous line potential and the theoretical ammeter current as a function of the phase difference between the grid and the line potentials. For example, at $\theta = 104°$ the plate potential before the discharge begins is 300 volts and if the arc were to start at this point and continue the rest of the cycle, the plate current ammeter would read 82×10^{-3} ampere. The heavy solid curve designated by $R_g = 0.3 \times 10^6$ ohms, shows the *observed* current as a function of the phase difference between the grid and line potentials. *It is of interest to notice that no current flows in the plate circuit if the phase difference is greater than 152°* although theoretically it should be possible to get a measureable current for phase differences up to at least 176°. This difference of 24° between the calculated and observed results, seems to indicate that a time of 1.1×10^{-3} sec. is required to build the positive ion sheath around the grid and particularly around the cathode so as to allow the full current to flow. On this basis the dotted line shown in Fig. 8 gives the calculated current assuming a time lag of 1.1×10^{-3} sec. This curve is obviously in better agreement with the observations.

FIG. 8.



A.C. characteristic of an *FG*-17 thyratron $V_p = 220$ volts, 60 cycles.

This question of the time lag could be answered definitely by experiments using a cathode ray oscillograph and a variable frequency generator. Other deviations between observed and calculated results might be due to the presence of a 180 cycle component in the line voltage which could also be examined with an oscillograph.

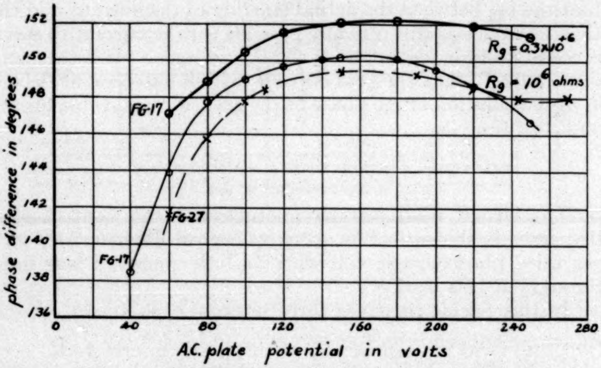
Observed results using a resistance R_g of 10^6 ohms instead of 0.3×10^6 came so close to those shown by the solid line that it would only confuse the picture to try to show them.

With a grid resistance R_g of 200×10^6 ohms, the capacity C_2 of Fig. 6 had to be made so small that the internal capacities of the tube C_0 and C_1 could not be neglected. Hull's[1] formula for the calculation of the phase angle α for this case is given in equation (11)

$$\alpha = \tan^{-1} \frac{R_g\omega(2C_2 + C_0)}{1 + R_g^2\omega^2(C_1 - C_2)(C_0 + C_1 + C_2)}. \qquad (11)$$

The observed results shown by the "dot-dash" line of Fig. 8, indicate that with this high value of R_g the plate current starts in abruptly with a value of 4×10^{-3} ampere instead of gradually with a value as low as 10^{-5} ampere or less as in the case of the lower grid resistance. The true phase of the grid is probably given by the current value on the solid line, showing that the grid current which has been neglected is responsible for an increase in the phase shift at the start of about 10°. The abruptness of the starting current foreshadows the result that with very high grid resistances or with small currents in photoelectric circuits, the advantages of the "phase shift" method of control as compared with the "critical potential"

FIG. 9.



Maximum phase difference between grid and plate potentials of a thyratron for operation on 60 cycles A.C.

method largely vanish. This point will be illustrated by experiments with photoelectric cell control of the thyratron.

In order better to understand this question of the apparent time lag in the starting of the thyratron, the critical value of the starting phase angle was measured as a function of the line voltage. For this purpose, an average current of 10^{-5} ampere in the 400 ohm plate circuit was taken as the "starting current." The results are shown in Fig. 9 by the heavy and light solid lines corresponding to grid resistances of 0.3×10^6 and 10^6 ohms respectively.

The dotted line shows the result obtained with $R_g = 10^6$ ohms on an *FG*-27 thyratron which is very similar to the *FG*-17 but of higher current carrying capacity. These curves show that the lag between the actual starting of the current and the time when it was theoretically possible for the current to start, is remarkably independent of the line voltage. It is therefore very unlikely that the grid current, which has been neglected in the calculation of the phase of the grid, is responsible for the observed time lag.

THYRATRON CONTROL WITH A PHOTOELECTRIC CELL.

(a) The Phase Shift Method.

The circuit used for the photoelectric cell control of a thyratron is shown in Fig. 10. A General Electric "*PJ*-23" gas filled photoelectric cell with its base removed was used throughout this work.

In this circuit there are three internal capacities:

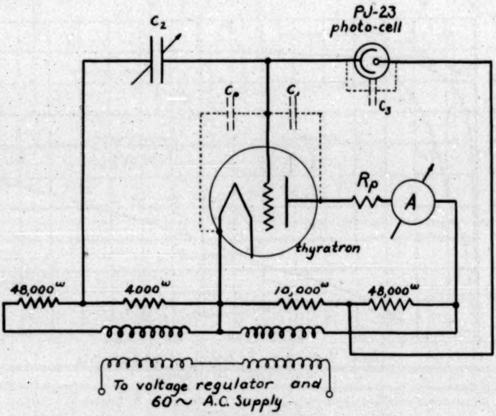
1. Grid to cathode, $C_0 = 10 \times 10^{-6}$ microfarad.
2. Grid to plate, $C_1 = 2 \times 10^{-6}$ microfarad.
3. Photocell anode to cathode, $C_3 = 1.6 \times 10^{-6}$ microfarad.

When C_2 was large the maximum potential across the photoelectric cell at any time during the cycle was 78 volts. This was near the maximum which could be used on this cell with safety because of the danger of starting a discharge in the photoelectric cell.

With the photoelectric cell in the dark the capacity C_2 was increased from a very small value to 29.5×10^{-6} microfarad. This value of C_2 exactly neutralized the internal capacities C_1

and C_3 and the thyratron stopped operating. With a value of C_2 smaller than 29.5×10^{-6} microfarad the grid was practically in phase with the line potential and the maximum current flowed in the plate circuit, but with C_2 larger than 29.5×10^{-6} microfarad the grid was practically 180° out of phase with the line potential.

FIG. 10

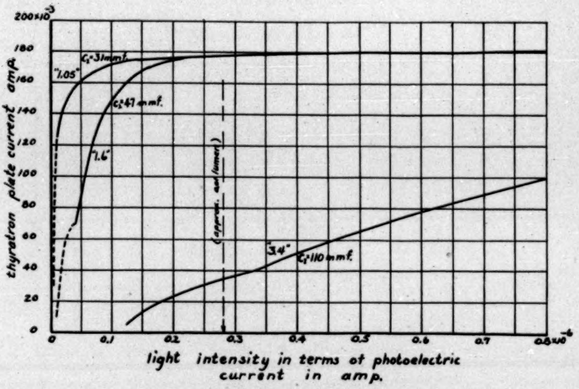


Circuit for photoelectric control of a thyratron using "phase shift" method.

The curve designated "1.05" in Fig. 11 was taken with $C_2 = 31 \times 10^{-6}$ microfarad, which is 1.05 times the neutralizing capacity. The ordinate for this graph gives the D.C. ammeter value of the plate current in the "load" circuit, while distances along the abscissa are proportional to the light intensity. The experiment was carried out by measuring the thyratron load current as a function of the lamp potential and later with a 45 volt battery and sensitive galvanometer connected to the photocell, the photoelectric current was measured as a function of lamp potential. The light intensity shown in Fig. 11 is given in terms of the photoelectric current which it produced.

When the light intensity was sufficient to give a photoelectric current of 3.5×10^{-9} ampere, the thyratron began to pass current in slow "flashes" taking place at the rate of about ten to fifteen per second. In ear phones it sounded as though the thyratron operated for part of a cycle, and then remained off for five or six cycles. With increasing light intensity these flashes disappeared and steady operation began with a plate current of 125×10^{-3} ampere which, according to Fig. 8, corresponded to the current flowing with the grid only 60° out of phase with the line.

FIG. 11.



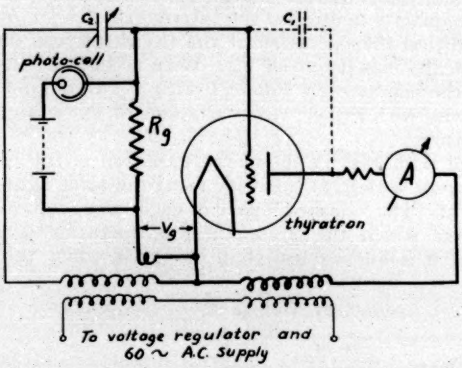
Results of photoelectric cell control of an *FG*-17 thyratron by phase-shift method. $V_p = 220$ volts, 60 cycles.

The increasing of C_2 to 47×10^{-6} microfarad or 1.6 times the neutralizing value, caused a decrease in the sensitivity of the system and reduced the tendency to "flash" as shown by the curve "1.6" of Fig. 11. A further increase in C_2 to 110×10^{-6} microfarad brought the thyratron current much more under the control of the light intensity with a further decrease in sensitivity.

(b) Thyratron Control with D.C. on the Photoelectric Cell.

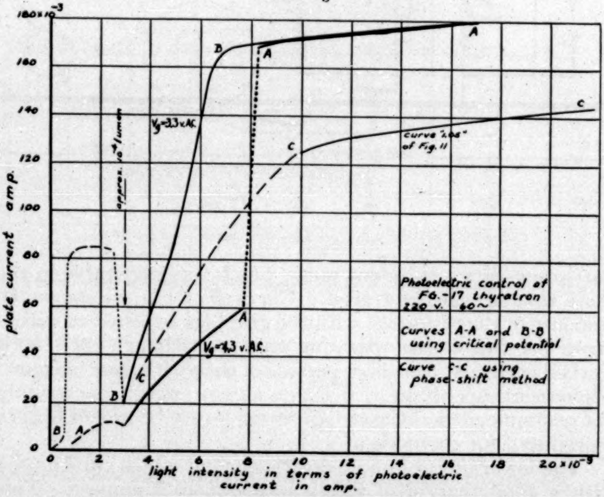
When it is necessary to obtain very high sensitivity in the thyratron response to light intensity, without the use of an amplifier, the circuit shown in Fig. 12 can be used.

FIG. 12.


C_2
C_1
photo-cell
R_g
V_g
A
thyratron
To voltage regulator and
60 ~ A.C. supply

Circuit for thyratron control by photoelectric cell using critical potential method.

FIG. 13.

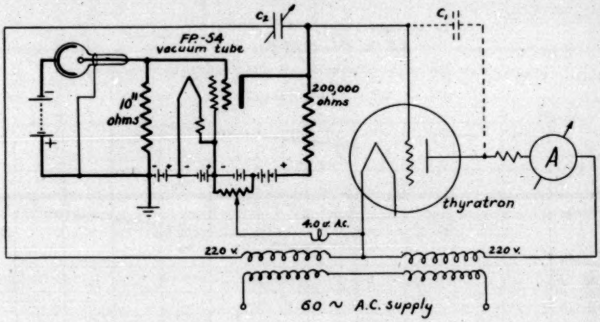


Results of photoelectric cell control of an *FG*-17 thyratron by "critical potential" method compared with "phase shift" method. Curves *A–A* and *B–B* for critical potential method and *C–C* for "phase shift" method. $V_p = 220$ volts, 60 cycles.

For the results shown in Fig. 13, the capacity C_2 was adjusted to exactly neutralize the internal capacity C_1. Under this condition the operation of the thyratron was under the control of the bias potential V_g. With no light on the photocell and the bias at -4.3 volts A.C., the circuit did not operate falsely even with rather wide variations of power supply and temperature.

Curve *A* of Fig. 13 shows the variation of the thyratron plate current with light intensity using the same light scale as in Fig. 11. The "dashed" part of each curve represents the range over which the thyratron was operating in periodic flashes at a frequency less than 60 cycles while the dotted part represents a transient range which was not stable in the sense that it could be traced. Curve *B* of Fig. 13 shows the response of the thyratron with the grid bias adjusted to within about 0.1 volt of the operating value. Although the circuit worked perfectly over short periods of time with this "trigger" adjustment, operation with such a narrow margin is certainly not recommended. Curve "*C*" is the "1.05" curve of Fig. 11 reproduced for comparison.

FIG. 14.



Circuit for Thyratron control using low grid current amplifier *FP*-54.

The lower limit of photoelectric current which can be used with a good margin of safety is about 10^{-8} ampere. This amount can easily be produced with the light reflected from a galvanometer mirror. If applications arise in which it is necessary to operate a thyratron on much less than 10^{-8} ampere a vacuum tube amplifier should be used. The photoelectric cell must be designed as so to have a "dark current" which is considerably less than the controlling photoelectric current. Fig. 14 shows a circuit using the General Electric "*FP*-54 low grid current vacuum tube" [5] by which it is theoretically possible to obtain reliable operation of a thyratron with a photoelectric current of 10^{-11} ampere.

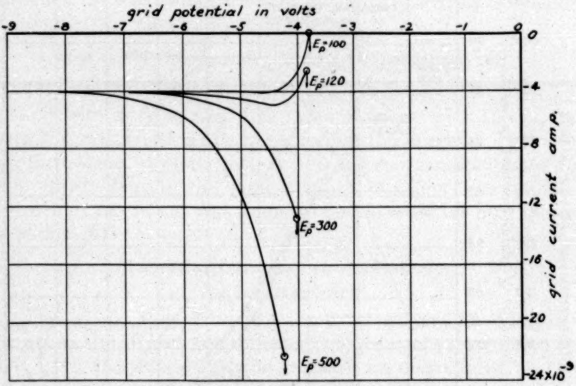
A high vacuum photoelectric cell can be used with either the "phase shift" or the "critical potential" method of control with very little change in the general form of the characteristics obtained but with considerable loss in sensitivity.

CHARACTERISTICS OF AN FG-27 THYRATRON.

(a) Static Characteristics.

The static characteristics of an *FG*-27 thyratron were taken using the methods described above and the circuit shown in

FIG. 15.



FG-27 thyratron—grid current before discharge.

Fig. 1 The results were very similar in character to those obtained on the *FG*-17 and are shown in Figs 15 and 16.

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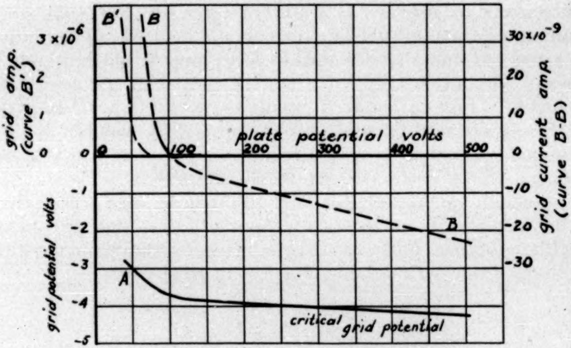
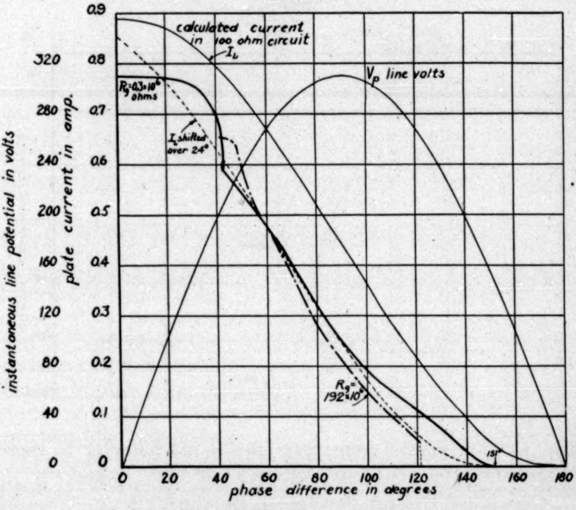
[5] Metcalf and Thompson, *Phys. Rev.*, 36, 1489 (1930).

FIG. 16.



FG-27 thyratron—Grid potential and grid current before discharge at critical point.

FIG. 17.



A.C. characteristics of an *FG*-27 thyratron—220 volts, 60 cycles.

By comparing Fig. 15 with Fig. 2 and Fig. 16 with Fig. 5, it is obvious that there are no significant differences between the general forms of these characteristics. The relation between the plate current and the grid current before the discharge began was found to be linear as in the case of the *FG*-17 illustrated by Fig. 3.

(b) Dynamic Characteristics.

The dynamic characteristics of the *FG*-27 also showed a very close similarity to those of the *FG*-17. The curves of Fig. 17 should be compared with those of Fig. 8. The circuit used is shown in Fig. 6. Equation 10 was used to calculate the line current as a function of starting phase using a plate resistance R_p of 100 ohms instead of 400 ohms as above.

Again it will be noticed that the calculated current flow without introducing the time lag hypothesis does not agree with the observations, but if it is assumed that a time of 1.1×10^{-3} sec. is required to start the discharge, the observed and the calculated curves agree fairly well. The fact that this time lag was independent of the plate potential, is demonstrated by the curve shown in Fig. 9.

FG-27 THYRATRON CONTROL WITH A PHOTOELECTRIC CELL.

The results obtained with the *FG*-27 in photoelectric control circuits were so near like those obtained with the *FG*-17 that it is not worth while to reproduce the curves. The only significant fact is that, with the circuit constants adjusted to give approximately the same margins of safety against false operation, the *FG*-27 was found to be less sensitive by a factor of about two.

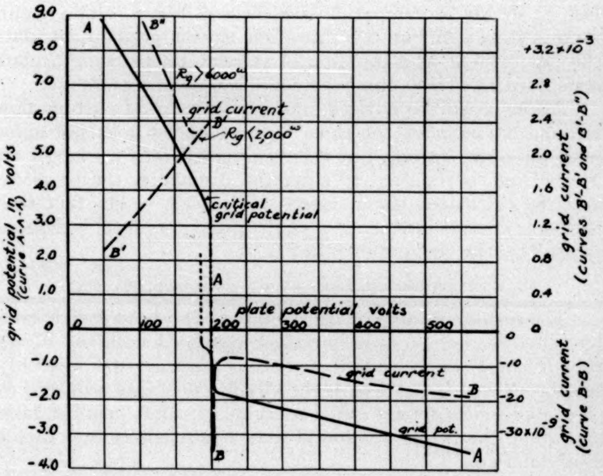
CHARACTERISTICS OF AN FG-67 THYRATRON.

(a) Static Characteristics.

The *FG*-67 thyratron has the same current carrying capacity as the *FG*-27 but differs in mechanical construction in that both the anode and the cathode are surrounded by the grid and the spacing between the grid and the anode is much less than in the *FG*-27. This mechanical difference causes an increase in the internal capacities of the tube C_0 and C_1 of Fig. 6. The measured values of these capacities were $C_0 = 20 \times 10^{-12}$ farad and $C_1 = 14 \times 10^{-12}$ farad. While the *FG*-27 and the *FG*-17 were designed as "controlled rectifiers" the *FG*-67 has been designed for "inverter" work. A number of useful inverter circuits are shown by Hull.[1] These circuits and slight modifications of them will undoubtedly find many uses in the physics laboratory where a source of pulsating direct current power is needed.

The static characteristics obtained on an *FG*-67 using the methods outlined above are shown in Figs. 18, 19 and 20.

FIG. 18.



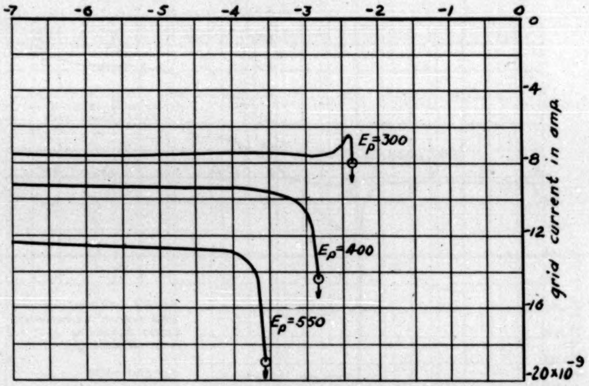
FG-67 thyratron (Condensation temp., 47.5° C.)—Grid potential and grid current at critical point

Figure 18 shows the critical grid potential and critical grid current as a function of the D.C. line potential. The curves here show a very marked difference when compared with those for the *FG*-17 and *FG*-27 of Figs. 5 and 16. At about 200 volts the critical grid potential suddenly changes from positive to negative values as the line potential is raised and the grid current required to operate the thyratron changes from 2.4×10^{-3} to -8×10^{-9}, a change in magnitude of almost a million. The variation of grid current with grid potential is shown for various plate potentials above 200 volts in Fig. 19.

These curves have much the same general form as those shown in Figs. 2 and 15.

With a plate potential of 160 volts the grid current characteristic is much more complicated. This is shown in Fig. 20.

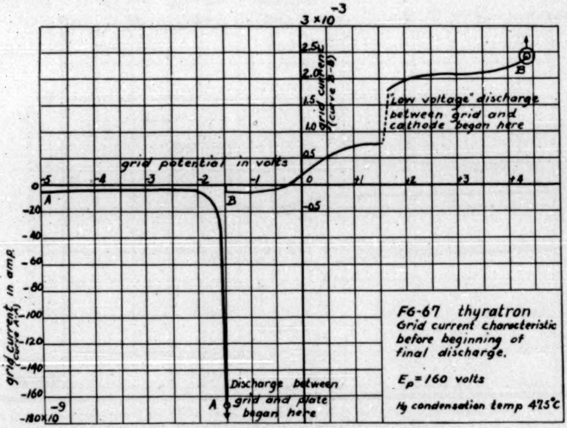
FIG. 19.



FG-67 thyratron—Grid current before discharge (Condensation temp., 47.5° C.).

With high negative grid potentials the grid current follows the generally expected curve showing the effect of the increase in positive ion current between -2 and -1.5 volts. At -1.5 volts a discharge developed between the *grid and the plate* which resulted in a sudden increase in the grid current from 160×10^{-9} to 0.13×10^{-3}. In spite of this large ion current, a space charge sheath did *not build up around the grid* and the thyratron did not really operate. At -0.2 volt the number of electrons coming from the cathode to the grid was equal to the number of positive ions, making the net current zero. At a grid potential of $+1.5$ a "low voltage discharge" suddenly developed between the grid and the cathode. The characteristic "blue glow" showing the predominance of the 5461 Å, 4358 Å and the 4047 Å lines of the triplet series gradually became stronger with increasing grid potential until at $+4.4$ volts the full discharge in the thyratron took place and a complete sheath formed around the grid which caused it to lose control. With lower line potentials still more complicated forms of the grid current characteristic were found but since a detailed knowledge of these is of no particular value they will not be described.

FIG. 20.



FG-67 thyratron—Grid current before beginning of final discharge—E_p = 160 volts (Condensation temp., 47.5° C.).

Four *FG*-67 thyratrons showed characteristics very similar to those shown above. The plate potential at which the critical grid potential crosses over from positive to negative values is a *function of the condensation temperature.* Figure 21 shows the observed relation between the "cross-over" potential and the condensation temperature as measured by a thermocouple placed in contact with the glass wall of the thyratron directly above the base. With the grid entirely disconnected or "free," the plate potential was raised very slowly until the discharge began. The critical value of plate potential found in this way was equal to the "cross-over" potential shown in Fig. 18.

From the curve of Fig. 21, it is easy to see that a change of temperature of only a few degrees may cause a given thyratron system to fail to operate unless the grid control circuit is capable of furnishing *milliamperes* of grid current. It was this particular difficulty which prompted the undertaking of this study of thyratrons.

FIG. 21.

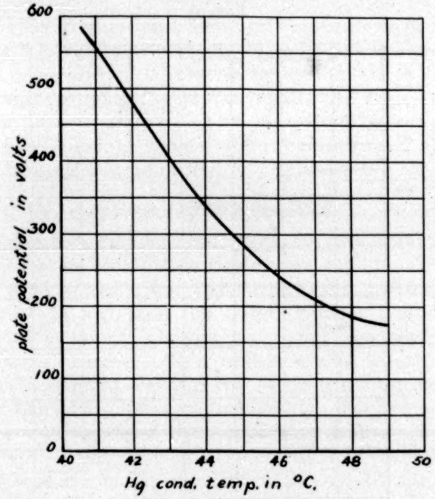


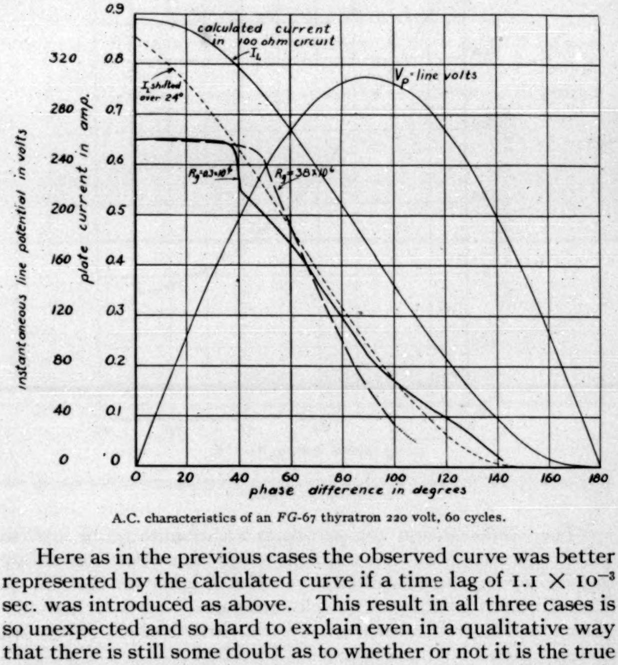
Plate potential for "free grid" operation of an *FG*-67 thyratron as a function of mercury condensation temperature.

The condensation temperature was found to be 25° to 28° C. higher, than the ambient temperature for the *FG*-27 and *FG*-67 thyratrons and about 17° C. higher for the *FG*-17. The ambient temperature was measured with a mercury thermometer at a distance of about three inches. Since all measurements were made in a shielded box 18″ × 18″ × 15″, the air circulation was not as good as it would have been with the tubes unshielded. For applications where only a small power input to the grid is available using the *FG*-67 thyratron with plate voltages between 200 and 500 volts, care must be used to keep the tubes warm enough during use to maintain a condensation temperature between 50° and 60° C.

(b) Dynamic Characteristics of an FG-67 Thyratron.

The dynamic characteristics of the *FG*-67 thyratron as a "controlled rectifier" were measured using the methods described above and the results are shown in Fig. 22.

FIG. 22.



A.C. characteristics of an *FG*-67 thyratron 220 volt, 60 cycles.

Here as in the previous cases the observed curve was better represented by the calculated curve if a time lag of 1.1×10^{-3} sec. was introduced as above. This result in all three cases is so unexpected and so hard to explain even in a qualitative way that there is still some doubt as to whether or not it is the true explanation of the observations. All that can be said for this "time lag hypothesis" is that it does agree with the observations to date. The experiments have not been of a kind, however, that make this conclusion unavoidable. Observations should be taken using an oscillograph, because if it is true that it requires 10^{-3} sec. to start a thyratron, this is just as important a fact to know in many applications as is the fact that it requires 10^{-4} sec. to stop it and restore control to the grid.

TECHNICAL SUGGESTIONS.

(a) Shielding.

In all thyratron circuits using grid resistances of 10^6 ohms or greater it is well to provide shielding because power circuits in neighboring apparatus can cause oscillations to be superimposed on the normal grid potentials and thus cause uncertain or false operation. This suggestion also applies to "phase shift" circuits, in case the capacities used are of the order of .004 microfarad or less.

(b) Design of a Small Variable Capacity.

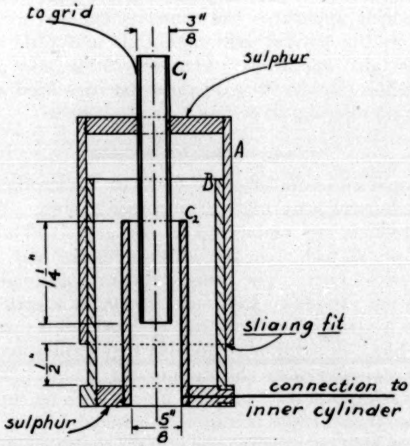
For capacities smaller than 50×10^{-6} microfarad, cylindrical condensers were made from brass tubing. The inside cylinder (which was connected to the grid) had an outside diameter of 3/8 inch and the outer cylinder had an inside diameter of 5/8 inch. The inner cylinder was made in four sections 5 cm., 10 cm., 15 cm. and 20 cm. in length and supported on a straight vertical rod of hard rubber which was held in a block of sulphur to furnish high insulation between the inner cylinder and the supporting frame. The outer cylinder was insulated by bakelite blocks from its support and arranged so that it could be raised or lowered definite amounts while it was held concentric with respect to the inner cylinder. The main support was connected to the cathode or the ground connection and the outer cylinder connected to the high potential. This construction eliminated any leakage current across the insulators from the "high potential" cylinder to the grid connection. The capacity could be varied by putting in various lengths of the inner cylinder (from 5 cm. to 50 cm.) and also by the movement of the outer cylinder with respect to the inner. The standard formula given in equation (12) which neglects the end effect in a cylindrical condenser was found to hold very well for this condenser.

$$C = \frac{0.2416\,l}{\log_{10}\dfrac{r_1}{r_2}}. \qquad (12)$$

Where l is the length in cm., r_1 is the inside radius of the outer cylinder and r_2 is the outside radius of the inner cylinder, the capacity C is then given in micro-microfarads.

The cross section of a second condenser used for the very small capacities is shown in Fig. 23.

FIG. 23.



Cylindrical condenser with approximate range 0.5 to 5×10^{-12} farad.

This condenser is made of four pieces of brass tubing, C_1 the inner cylinder, C_2 the outer cylinder of the condenser and A and B the sliding support. The maximum capacity obtained with this condenser was about 5×10^{-12} farad and served very satisfactorily for the neutralizing condenser C_2 in Fig. 12.

(c) High Resistances.

High resistances made using Higgens India ink have been described in a previous paper,[3] but it is perhaps necessary to call attention to the fact that such resistances do not follow Ohm's law with high potentials unless the line is made sufficiently broad. Resistances made with "Aquadag" [6] are used by some for the production of high resistances but the author has not yet given this resistance material a test.

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[6] A graphite product of the Acheson Oildag Co. of Port Huron, Mich.

CONCLUSION.

Although the characteristics of thyratrons shown in this paper do not cover all of the important details of thyratron operation, it is hoped that the information given will be of value to those who have already tried to make use of the thyratron and have run into minor difficulties, and also serve further to introduce the thyratron and encourage physicists to make use of this new and very valuable thermionic device, which has so many possible applications in the present day scientific laboratory.

Since writing of this article I have found certain interesting facts concerning the early development of the thyratron which are not well known. During the year 1913 Prof. George W. Pierce carried out a series of very interesting investigations with gas filled tubes containing a cathode, grid, and anode. These tubes were used as amplifiers and detectors in somewhat the same way as the tubes described by Eugen Reisz (E. T. Z. 34, 1356 (1913)). The theory of operation, as understood at that time, is given in considerable detail in the three United States patents 1,112,655; 1,087,180 and 1,112,549 all of which were applied for in the second half of 1913. Very early in the year 1914, Prof. Pierce discovered the "thyratron properties" of these gas filled three-electrodes tubes much as we know them today and filed an application for a patent on March 11, 1914, in which he described numerous circuits including one using a selenium cell about which he writes: "This form of device is very sensitive and it has been found that the light of a candle across a room focused on the selenium cell is sufficient to effect the control of several amperes in the controlled circuit." (U. S. Patent 1,450,749.)

The Frequency of Occurrence of the Disintegrative-Synthesis of Oxygen 17 from Nitrogen and Helium. W. D. HARKINS AND A. E. SCHUH. (*Phys. Rev.*, April 1, 1930.) By shooting very rapid α-particles from thorium C′ into a Wilson cloud chamber containing nitrogen gas Harkins and Shadduck a few years ago succeeded in finding two instances in which oxygen was formed synthetically by the union of an α-particle to a nitrogen nucleus. It took 250,000 α-particles of 8.6 cm. range to produce the two cases. 135,000 particles of 4.9 cm. range furnished no single synthesis.

In this set of experiments the α-rays came from thorium C and C′ and ploughed their way through nitrogen gas in a cloud chamber. 39,000 photographs were taken, each giving two views at right angles. Each photograph showed about 10 tracks so that 390,000 α-particles were used and their paths recorded. Of these 250,000 were of long range. "The 390,000 photographs were projected on a screen, one at a time, usually with two observers present." It was by so lengthy and wearying a procedure that there were discovered two cases in which oxygen 17 was synthesized. A reproduction of one of the photographs is given. It seems that the nitrogen atoms that enter into such unions are of mass 14 and isotopic number 0.

G. F. S.

THE EFFECT OF RADIOACTIVE RADIATIONS UPON EUGLENA.*

BY

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BARTOL RESEARCH FOUNDATION.
Communication No. 52.

An examination has been made of the rate of death of euglena cells when exposed to the alpha particle radiation from radium emanation dissolved in the containing liquid. It was found that the rate of death of the cells was proportional to the strength of the dissolved emanation and to the number of live euglena cells present, a conclusion in harmony with the view that death of a cell is caused by a single impact of some sensitive region with an alpha particle. The theory of the case where two impacts of the sensitive region with an alpha particle are necessary to cause death, has been worked out with a generality which allows for a recovery of the cells between the two impacts. It is found that the results of the experiment are inconsistent with such a hypothesis. From the experimental data, it is possible to calculate the size of the sensitive entity which when struck by the alpha particle causes death to the cell. The diameter of this entity comes out about equal to that of the nucleus of the euglena cell.

Introduction.—The effect of radioactive radiations upon cells, especially upon cancer cells, was studied soon after radioactivity was discovered, but the complete story of just what happens when a cell is killed by these radiations is not yet understood. It was with the object of obtaining further information upon this matter that the experiments herein recorded were carried out. Euglena cells were chosen in the first instance because they were readily obtainable, and because it was readily possible to detect death since, in the living state, they maintained a lively motion.

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* The investigation was carried out, through the aid of a grant, under the auspices of the Cancer Research Fund, Graduate School of Medicine, University of Pennsylvania. The experiments were conducted by the junior author under the direction of the senior author, who is also responsible for the theoretical treatment.

The immediate purpose of the investigation was to obtain as much information as possible on (*a*) the question of whether a single impact or several impacts with an alpha particle are necessary to kill a cell, (*b*) the size of the entity, or vital spot, if there be such a region on the cell, which must be hit by the α particle in order to produce death. The general procedure involved dissolving a measurable amount of radium emanation in the water which contained the Euglena, and then observing the rate at which the cells died as a result of the actions of the radiations.

Case 1.—The simplest hypothesis, which we shall refer to as Case 1, is to the effect that there is, in the cell, a sensitive region of surface area S, such that if an α particle enters S death will occur. Under these conditions, we have

$$-\frac{dn_1}{dt} = Nn_1,$$

so that

$$n_1 = \bar{n}e^{-Nt}, \qquad (1)$$

where n_1 is the number of euglena cells living at the time t, $\bar{n}$ is the number at $t = 0$, and N is the number of α particles entering the sensitive area per second. In the appendix to this paper, N is shown to be given by

$$N = \frac{r_0QS}{4} \qquad (2)$$

where Q is the rate of emission of α particles per c.c. of liquid, and r_0 is the range of the α particles in the liquid.

The characteristic feature of the foregoing hypothesis is that it results in a linear relation between log n_1 and t with the slope of the graph equal to N. In other words, $-(1/n_1)dn_1/dt = N$, and is therefore a constant independent of the time.

The value of N determined from the slope of the graph gives, through (2), the area S of the surface surrounding the sensitive region, and so through the relation

$$4\pi\epsilon^2 = S \qquad (3)$$

we can determine the radius ϵ of a sphere having the same surface area as the surface S.

Case 2.—In this case, we consider a situation where two impacts of an α particle with the sensitive element of the cell are necessary to cause death, and the situation becomes more complicated. Moreover, we ought, for generality, to admit the possibility of a cell recovering after the first impact, and before the second, so that the effect of the first impact is lost. When we take account of all these considerations, we have to consider several states which we shall designate as states 0, 1, 2, as follows:

State 0 refers to a cell which has suffered no collision with α particles, or which has recovered from a collision suffered.

State 1 refers to a cell which has suffered one collision, and has not yet recovered.

State 2 refers to a cell which has suffered two collisions without recovery between and is consequently dead.

Let n_1 be the number of euglena cells per c.c. which are active at any instant t. It is shown in the appendix to this paper that

$$-\frac{1}{n_l}\frac{dn_l}{dt} = \frac{(\alpha^2 - \beta^2)(e^{2\beta t} - 1)}{(\alpha + \beta)e^{2\beta t} - (\alpha - \beta)}, \qquad (4)$$

where

$$\alpha = N + \frac{\lambda}{2}; \qquad \beta = \left(N\lambda + \frac{\lambda^2}{4}\right)^{1/2} \qquad (5)$$

and λ is the factor by which we must multiply the number per c.c. which have suffered only one collision in order to obtain the number which recover per second.

It follows from (4) that [1]

$$\frac{1}{n_l}\frac{dn_l}{dt} = 0 \qquad \text{at } t = 0$$

in contrast to the result

$$\frac{1}{n_l}\frac{dn_l}{dt} = -N \qquad \text{at } t = 0 \text{ for case 1.}$$

Experimental Procedure.—Trouble of a minor nature was experienced in the first measurements on account of certain peculiar characteristics of the euglena. The presence of metals in the container seemed to poison them and cause death. Moreover, when the container had corners, or cave-like cavities, the euglena would seek out such places almost as though they wished to hide themselves. Several types of euglena containers were tried, and the one finally adopted was made in the following way: Glass plates A, B, and C, Fig. 1, are three microscope slides. A hole about 1.5 cm. in diameter was cut in A, and a slit about 1.5 mm. wide was made between this hole and one side of the plate. Plate B was cemented to the bottom of A with Canada balsam, and the combination was baked at slightly over 100° C. for a few minutes. The balsam squeezed into the small shallow circular cup thus formed was scraped and dissolved off. To facilitate the subsequent countings, concentric circles were etched on plate C, the spacing between them being slightly less than the diameter of the field of view of the microscope. Plate C was fixed to the top of plate A with a heavy stop cock grease and with the etched circles down and concentric with the shallow cup. A small thin flat circular liquid container was thus obtained which had a small rectangular hole leading to the outside. The euglena water was introduced into this container with a pipette, and the euglenas were counted at regular intervals to make sure that the conditions were satisfactory for their existence. Radium emanation in a small short glass tube was then introduced into the container and put in the position shown in Fig. 2. Counts at regular intervals were again made to ascertain that right conditions still existed and to note possible effects due to γ and β rays.

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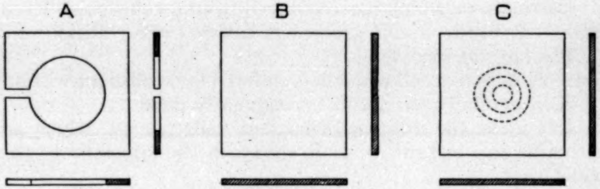
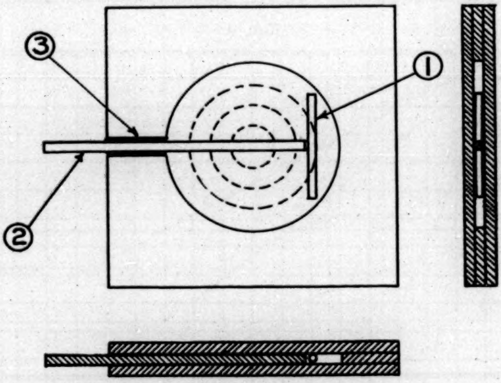
[1] This result may also be seen directly from the fundamental differential equation governing the phenomena (see appendix).

FIG. 1.



A small glass rod was then inserted in the rectangular hole, one end touching the emanation tube as shown in Fig. 2. Heavy stop cock grease was put in the space between this rod and the hole to prevent emanation from escaping after the containing tube was broken. On pushing the small glass rod inwards, the emanation tube was broken, and the released emanation dissolved in the euglena water to an extent calculable from theoretical considerations. Counts were again made. In all these measurements a "Control" container with euglena but without radium emanation was always used. The strength of the emanation used was measured by its γ ray activity as recorded by a gold leaf electroscope calibrated by a radium standard. The emanation was, of course, allowed to come to equilibrium with its products before standardization and use.

FIG. 2.



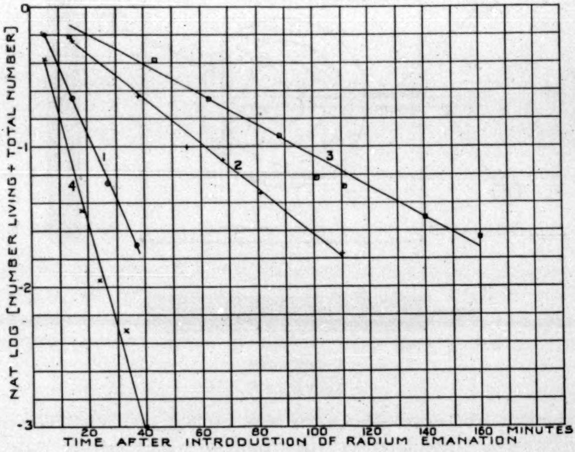
1. Emanation tube.
2. Glass rod.
3. Heavy stop cock grease.

An empty glass tube similar to the emanation tube was also introduced into one container and broken inside to ascertain if there was any effect due to pressure changes in the euglena water when the small rod "plunger" broke the emanation tube.

In all the death rate calculations, allowances were made for slow cell division as determined in the "control" container.

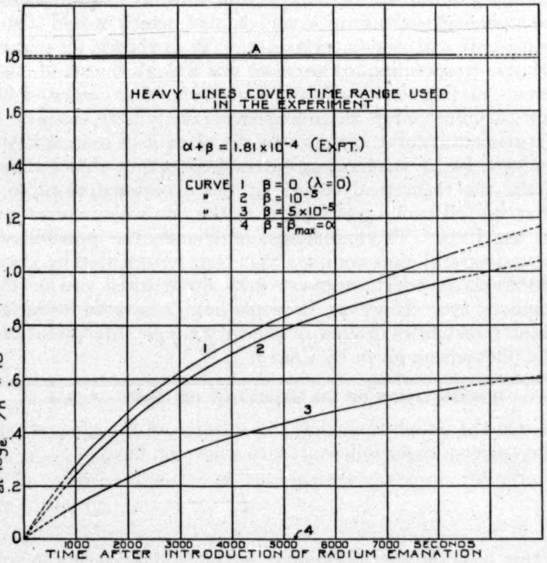
Experimental Results.—It was found that bombardment by the β and γ rays before the emanation tube was broken did not kill the euglena at a rate which could be distinguished from the uncertainties of the measurements. The death caused by α particles, however, entirely outweighed such uncertainties. Fig. 3 shows the values of log $n_l/\bar{n}$ plotted against the time, for several strengths of emanation, after correction, in each case, for increase by cell division. $\bar{n}$ refers to the number of live euglena initially present. The slopes of the graphs give, for each case, the values of $(1/n_l)dn_l/dt$; and, the linearity of the graphs shows that this slope is constant for each case. The results are thus consistent with the type of phenomena we have classified as Case 1; and, the slopes of the graphs give the corresponding values of minus N.

FIG. 3.



Of course, one might conceivably suppose that, since the experiments did not extend right up to $t = 0$, it might happen that the curves, if plotted accurately up to that limit, might show a bend near the limit in such a manner as to be consistent with a zero value of $(1/n_l)dn_l/dt$ there. It might be supposed, in fact, that all the peculiarities of the curve might lie near $t = 0$, leaving, for higher values of t, only the simple linear relations found. Such a situation is very unlikely; but, in order to rule it out entirely we may proceed as follows: At $t = \infty$, equation 4 leads to the result

FIG. 4.



$$\frac{1}{n_l}\frac{dn_l}{dt} = -(\alpha + \beta),$$

so that even if the slopes of the curves in Fig. 3 had not been constants for lower values of t, they would approach finite and constant values for larger values of t, and the slopes would give the values of $-(\alpha + \beta)$. The experiments thus give the proper values of $(\alpha + \beta)$, independently of uncertainty which may exist in extrapolations from the measurements near $t = 0$. If then, for a fixed value of $(\alpha + \beta)$ we draw the curves for the totality of values of β, this singly infinite set of curves will extend over the range of all of the doubly infinite set of curves which could be obtained by assigning all values to N and λ, and which would also be consistent with the experiments. Fig. 4 shows, for one case (that corresponding to the curve 3 of Fig. 3), the set of curves corresponding to the value of $(\alpha + \beta)$ for that case, and for a set of values of β extending over the entire range. The experimental curve is shown by A. It will be seen that since curve 1, Fig. 4, is a limiting curve of the set, no choice of β can make the theoretical curves fit the experimental curve, so that we fall back upon Case 1 as the one which corresponds to the facts. There remains, of course, the possibility of situations still more complex than that represented by Case 2, situations in which recovery may occur after two or more impacts, etc. However, it seems unnecessary to investigate these possibilities in view of the very simple interpretation of the phenomena given by Case 1.

INTERPRETATION OF THE RESULTS IN THE LIGHT OF CASE 1.

On the assumption that the solution of the emanation in the euglena water follows Henry's law, we have

$$\frac{p_a}{x_a} = k, \tag{6}$$

where p_a is the partial pressure of the emanation in the space outside the solution, x_a is the mole fraction of emanation in solution, and k is a constant, characteristic of the solution, and equal to 3.97×10^6,[2] for the case where p_a is in atmospheres. The quantity x_a may be more specifically defined as

$$x_a = \frac{N_a}{N_a + N_o},$$

where N_a is the number of molecules of emanation per c.c. in solution, N_o is the number of molecules in a cubic centimeter of water. The volume of 1 millicurie of radium emanation at one atmosphere is 5.85×10^{-7} c.c., so that the number of molecules of emanation in a millicurie is the same as the number of molecules of any gas in 5.85×10^{-7} c.c.[3] at normal temperature and pressure, and is thus very small compared with the number of molecules in a c.c. of water, or, even in say 10^{-3} c.c. of water. Hence, since in the experiments, the amount of emanation in solutions is always less than the total amount of emanation used, and since the volume of euglena water was of the order of 10^{-3} c.c. and the total emanation used in an experiment was of the order of one or two millicuries, it is perfectly obvious that N_a/N_o was small compared with unity, so that we may replace x_a by N_a/N_o, and (6) then gives

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[2] P. 257, Int. Cr. Tables, Vol. III.

$$N_a = \frac{N_o p_a}{k}.$$

Since $N_o = 6.2 \times 10^{23}/18$, we have, on substituting for k the value given above,

$$N_a = 0.87 \times 10^{16} p_a. \tag{7}$$

Now

$$p_a = \bar{N}_a RT/1.01 \times 10^6$$

where R is the gas constant per molecule, $\bar{N}_a$ is the number of molecules of emanation per c.c. in the water, and the constant 1.01×10^6 is to allow for p_a being in atmospheres. We then have,[4] from (7),

$$\frac{N_a}{\bar{N}_a} = \frac{0.87 \times 10^{16} RT}{1.01 \times 10^6} = 0.86 \times 10^{10} RT. \tag{8}$$

If v_1 is the volume of the liquid in the container, and v_2 the volume of the air-space in the container, the total number of

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[3] Appendix—Radioactive Measurements (Makower & Geiger).

[4] Putting $R = 1.35 \times 10^{-16}$, and $T = 293°$ we find

$$\frac{N_a}{\bar{N}_a} = 3.4 \times 10^{-4}.$$

It is thus of interest to observe that only a very small fraction of the emanation goes into solution.

emanation molecules originally in the emanation tube is equal to $N_a v_1 + \overline{N}_a v_2$. Hence, if P is the partial pressure of the emanation in the original tube in dynes per square cm., and if V is the volume of the tube,

$$PV = (N_a v_1 + \overline{N}_a v_2)RT.$$

Now 1 millicurie of radium emanation at one atmosphere occupies[5] 5.85×10^{-7} c.c. Hence, since 1 atmosphere equals 1.01×10^6 dynes per square cm.,

$$PV = 1.01 \times 10^6 \times 5.85 \times 10^{-7} J = 0.59J,$$

where J is the number of millicuries originally in the emanation tube. Hence

$$N_a v_1 + \overline{N}_a v_2 = \frac{0.59J}{RT}. \tag{9}$$

Combining (8) and (9) we have

$$N_a\left(v_1 + \frac{v_2 \times 10^{-10}}{0.86RT}\right) = \frac{0.59J}{RT}.$$

Since v_1 is comparable with v_2, and since $0.86RT \times 10^{10}$ is equal to 3.4×10^{-4} at $T = 293°$, the term containing v_1 may be neglected, and we have, approximately,

$$N_a = \frac{0.86 \times 0.59 \times J \times 10^{10}}{v_2} = \frac{0.51J}{v_2} \times 10^{10}.$$

The transformation constant of radium emanation is 2.08×10^{-6} sec^{-1}. Hence, the number of α particles liberated per c.c. per second in the water is

$$Q = 2.08 \times 10^{-6} N_a = 1.06 \times 10^4 \frac{J}{v_2}.$$

Hence, from (2)

$$N = \frac{1.06 r_0 SJ \times 10^4}{4v_2} = \frac{2.65 r_0 SJ \times 10^3}{v_2}.$$

The range r_0 of an α particle in water is[6] 3.6×10^{-3} cm. Hence

$$N = 9.54\frac{SJ}{v_2}. \tag{10}$$

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[5] Appendix—Radioactive Measurements (Makower and Geiger).

[6] P. 368, Int. Cr. Tab., Vol. I.

It, of course, results that Nv_2/J should be constant for the various experiments, the value of the constant being, in fact, $9.54S$.

Table I shows the results of four experiments with different strengths of radium emanation.

TABLE I.

Minus Slope of Graph N Sec^{-1}.	v_2 cc.	J millicuries.	$\frac{Nv_2}{J}$.
7.9×10^{-4}........	1.2×10^{-2}	1.35	7.0×10^{-6}
2.74×10^{-4}........	"	0.51	6.5 "
1.81×10^{-4}........	"	0.30	7.3 "
12.5×10^{-4}........	"	1.97	7.6 "

The constancy of the numbers in the last column is evidence of the harmony of the experiments. The average value of the numbers in the last column is 7.1×10^{-6} so that

$$\begin{aligned} 9.54S &= 7.1 \times 10^{-6}, \\ S &= 7.4 \times 10^{-7}. \end{aligned}$$

The radius ϵ of a sphere having the same surface area as the surface S, is given by (3) and amounts to

$$\epsilon = 2.4 \times 10^{-4} \text{ cm.}$$

The average radius of a euglena cell is about 1.2×10^{-3} cm., so that ϵ is about one-fifth of the radius of the cell. As a matter of fact, the size of the sensitive entity seems to be about equal to that of the nucleus of the cell, which has a mean radius of the order one-fifth of the radius of the cell.

APPENDIX.

Derivation of the relation $N = r_0QS/4$.—If Q is the rate of emission of α particles per c.c. of liquid, the number entering per second through an element dS of S within the solid angle $2\pi \operatorname{Sin} \theta d\theta$ inclined at the angle θ to the normal to dS is

$$QdS \int_0^{r_0} \frac{dr}{4\pi r^2} \cdot 2\pi r^2 \operatorname{Sin} \theta \operatorname{Cos} \theta d\theta,$$

so that the total number dN entering through dS per second is

$$dN = QdS \int_0^{r_0} \frac{dr}{4\pi r^2} \int_0^{\pi/2} 2\pi r^2 \operatorname{Sin} \theta \operatorname{Cos} \theta d\theta$$
$$= \frac{r_0 QdS}{4}.$$

and the total number entering the surface S per second is

$$N = \frac{r_0 QS}{4}.$$

Derivation of Equation (4) and Allied Relations.—Let $\bar{n}$ be the number of live euglena cells per c.c. at $t = 0$, and let n_0, n_1 and n_2 be the numbers per c.c. in states zero, one and two, respectively, at any subsequent time t. Let n_l be the number alive at any instant, so that

$$n_l = n_0 + n_1 = \bar{n} - n_2. \tag{11}$$

The equations which control the progress of the phenomena are

$$\frac{dn_0}{dt} = -Nn_0 + \lambda n_1, \tag{12}$$

$$\frac{dn_1}{dt} = -\frac{dn_0}{dt} - Nn_1, \tag{13}$$

$$\frac{dn_2}{dt} = Nn_1, \tag{14}$$

where λ is the constant of recovery.

Incidentally, it will be observed that since $n_1 = 0$ at $t = 0$ and in view of (14) and (11) $\frac{1}{n_l} - \frac{dn_l}{dt} = 0$ when $t = 0$.

Of course, it must be admitted that the foregoing formulation is only an ideal one; and, in the case of situations of this kind, the complete facts would probably demand a consideration of "partially recovered" cells in place of a sharply defined state corresponding to State 1. However, it is probable that the main features of the actual problem would be represented, approximately, by the ideal problem.

From (12)

$$\frac{d^2 n_0}{dt^2} = -N\frac{dn_0}{dt} + \lambda \frac{dn_1}{dt}. \tag{15}$$

From (12) and (13)

$$(N + \lambda)\frac{dn_0}{dt} + N^2 n_0 = -\lambda\frac{dn_1}{dt}. \qquad (16)$$

From (15) and (16)

$$\frac{d^2 n_0}{dt^2} + (2N + \lambda)\frac{dn_0}{dt} + N^2 n_0 = 0.$$

Hence

$$n_0 = Ae^{-(N+\lambda/2)t}e^{1/2\{(2N+\lambda)^2-4N^2\}^{1/2}} + Be^{-(N+\lambda/2)t}e^{-1/2\{(2N+\lambda)^2-4N^2\}^{1/2}}, \qquad (17)$$

i.e.

$$n_0 = Ae^{-(N+\lambda/2)t}e^{(N\lambda+\lambda^2/4)^{1/2}} + Be^{-(N+\lambda/2)}e^{-(N\lambda+\lambda^2/4)^{1/2}}.$$

Put

$$N + \lambda/2 = \alpha; \qquad (N\lambda + \lambda^2/4)^{1/2} = \beta. \qquad (18)$$

Then

$$n_0 = Ae^{-(\alpha-\beta)t} + Be^{-(\alpha+\beta)t}.$$

At

$$t = 0, \qquad n_0 = \bar{n} \qquad \text{and} \qquad \frac{dn_0}{dt} = -N\bar{n}.$$

Hence

$$\bar{n} = A + B; \qquad -(\alpha - \beta)A - (\alpha + \beta)B = -N\bar{n}.$$

Hence

$$A - B = \frac{\alpha\bar{n} - N\bar{n}}{\beta}$$

$$A = \tfrac{1}{2}\left[\frac{(\alpha + \beta)\bar{n} - N\bar{n}}{\beta}\right]; \qquad B = \tfrac{1}{2}\left[\frac{(\beta - \alpha)\bar{n} + N\bar{n}}{\beta}\right]$$

$$n_0 = \frac{\bar{n}}{2\beta}\left\{(\alpha + \beta - N)e^{-(\alpha-\beta)t} + (\beta - \alpha + N)e^{-(\alpha+\beta)t}\right\}$$

$$= \frac{\bar{n}}{2\beta}\left\{\left(\beta + \frac{\lambda}{2}\right)e^{-(\alpha-\beta)t} + \left(\beta - \frac{\lambda}{2}\right)e^{-(\alpha+\beta)t}\right\}. \qquad (19)$$

Hence, from (13)

$$\frac{dn_1}{dt} + Nn_1 = \frac{\bar{n}}{2\beta}\left\{\left(\beta + \frac{\lambda}{2}\right)(\alpha - \beta)e^{-(\alpha-\beta)t} + \left(\beta - \frac{\lambda}{2}\right)(\alpha + \beta)e^{-(\alpha+\beta)t}\right\}. \tag{20}$$

Also from (13) and (14)

$$n_1 = -n_0 - n_2 + \text{const.}$$

At

$$t = 0, \qquad n_1 = n_2 = 0 \qquad \text{and} \qquad n_0 = \bar{n}.$$

Hence, the constant is equal to $\bar{n}$, and

$$n_2 = \bar{n} - n_0 - n_1. \tag{21}$$

From (20)

$$n_1 = Ce^{-Nt} + pe^{-(\alpha-\beta)t} + qe^{-(\alpha+\beta)t}, \tag{22}$$

where

$$-p(\alpha - \beta) + Np = -\frac{\bar{n}}{2\beta}\left(\beta + \frac{\lambda}{2}\right)(\beta - \alpha)$$

and

$$-q(\alpha + \beta) + Nq = \frac{\bar{n}}{2\beta}\left(\beta - \frac{\lambda}{2}\right)(\beta + \alpha).$$

Hence

$$p = -\frac{\bar{n}(\beta + \lambda/2)(\beta - \alpha)}{2\beta(\beta - \lambda/2)}, \tag{23}$$

$$q = -\frac{\bar{n}(\beta - \lambda/2)(\beta + \alpha)}{2\beta(\beta + \lambda/2)}. \tag{24}$$

Since $n_1 = 0$ at $t = 0$ we have

$$C + p + q = 0. \tag{25}$$

But, from (23) and (24)

$$p + q = -\frac{\bar{n}}{2\beta(\beta^2 - \lambda^2/4)} \times [(\beta - \alpha)(\beta + \lambda/2)^2 + (\beta + \alpha)(\beta - \lambda/2)^2]$$

$$= \frac{-\bar{n}}{(\beta^2 - \lambda^2/4)}\left[\beta^2 + \frac{\lambda^2}{4} - \alpha\lambda\right].$$

On substituting in the square bracket for α and β from (18), we find

$$\beta^2 + \lambda^2/4 - \alpha\lambda = 0.$$

Hence $p + q = 0$ and consequently, from (25), we find $C = 0$. Equation (22) then gives

$$n_1 = pe^{-(\alpha-\beta)t} + qe^{-(\alpha+\beta)t}$$

and on substituting from (23) and (24) in (19), that equation becomes

$$n_0 = -\frac{p(\beta - \lambda/2)}{(\beta - \alpha)}e^{-(\alpha-\beta)t} - \frac{q(\beta + \lambda/2)}{(\beta + \alpha)}e^{-(\alpha+\beta)t},$$

since

$$n_l = \bar{n} - n_2.$$

So that, using (21),

$$n_l = n_0 + n_1.$$

We thus have

$$n_l = \frac{p(\alpha - \lambda/2)}{(\alpha - \beta)}e^{-(\alpha-\beta)t} + q\frac{(\alpha - \lambda/2)}{(\alpha + \beta)}e^{-(\alpha+\beta)t},$$

putting

$$p = -q,$$

$$n_l = p\left\{\frac{e^{-(\alpha-\beta)t}}{(\alpha - \beta)} - \frac{e^{-(\alpha+\beta)t}}{(\alpha + \beta)}\right\}.$$

Hence

$$-\frac{1}{n_l}\frac{dn_l}{dt} = (\alpha^2 - \beta^2)\frac{e^{-(\alpha-\beta)t} - e^{-(\alpha+\beta)t}}{(\alpha + \beta)e^{-(\alpha-\beta)t} - (\alpha - \beta)e^{-(\alpha+\beta)t}}$$

$$-\frac{1}{n_l}\frac{dn_l}{dt} = \frac{(\alpha^2 - \beta^2)(e^{2\beta t} - 1)}{(\alpha + \beta)e^{2\beta t} - (\alpha - \beta)}.$$

Third Coal Conference.—A third international conference on bituminous coal will be held at the Carnegie Institute of Technology in November 1931.

An invitation will be extended to scientists of all countries to take part in the meeting, which is the only one of its kind of international scope.

The program will include papers on carbonization, liquefaction and gasification of coal; by-products of coal; the mechanism of combustions; cleaning of coal and its preparation for the market; pulverized fuels; power plants, and domestic heating. The discussions will be confined to coal above ground. Beginning at the mouth of the mine, however, practically every phase of distribution and consumption will be treated by outstanding authorities in the several fields.

Announcement of this third world meeting comes in logical sequence to the previous congresses. The first conference was organized by President Baker of the Carnegie Institute of Technology in 1926 for the purpose of finding new uses for bituminous coal and especially to discuss the problem of liquefying coal to supplement the petroleum oil supply of the world. This meeting, although it was the first of its kind to be held, attracted 1700 scientists from thirteen different countries. Two years later followed the second congress which was broader in its scope, including discussions on pulverized fuel, low temperature carbonization of coal, rubber from coal, the hydrogenation of coal, and by-product nitrogen. Speakers during the two conferences have included Georges Claude, Dr. Friedrich Bergius, Prof. Franz Fischer, Dr. C. H. Lander, Dr. R. Lessing, General Georges Patart, Dr. Fritz Hofmann, and Dr. Karl Krauch. Papers of numerous other fuel technologists were presented at the meetings.

The published proceedings of the two conferences have been enthusiastically received, and they are now considered standard reference books on modern fuel technology. R.

NEON TUBE LIGHT AND FACTORS GOVERNING ITS LIFE.

BY

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Neon gas consists of atoms which exist by themselves. Each atom contains at its center a small massive body called the nucleus, which carries a minute electrical charge. Outside the nucleus there are electrons in different groupings of varying radii, which are usually thought to revolve around the nucleus in circular or elliptical orbits. These electrons carry individual negative charges, and in each neutral atom the total of the negative charges corresponding to the number of electrons is exactly equal to the positive charge upon the nucleus. When an atom has an electron removed from it, the electrical balance between the positive and the negative charges within the atom is destroyed. Thus the electron which has been removed carries only a negative charge, and the remaining atom a resultant positive charge. In this condition the atom is spoken of as ionized. The positive remainder is called the positive ion, and the electron is referred to simply as the electron. Thus the parts of the atom may be attracted or repelled by external electric charges.

In the neon tube there are, to begin with, a few ionized atoms. When the potential is impressed upon the electrodes of the tube, the positive ion is attracted to the cathode or negative terminal, and the negatively charged particle or electron is attracted to the anode. In the motion of these ions and electrons to the electrode of opposite sign, they encounter other atoms. The electron being light, and therefore moving at high velocity, often causes atoms with which it collides to become ionized by removing from them, by the force of the impact, one or more electrons. Thus there takes place, by the impact of electrons and ions with the atoms of the gas, a progressive ionization along the length of the tube.

Eventually the positive ions strike upon the cathode and there lose their positive charge. Likewise, the electrons strike upon the anode. When the positive ions strike the cathode, electrons are liberated, which leave the cathode and move in the opposite direction to that of the positive ions. Thus there is established a flow of charged particles, which accounts for the conduction of electricity through the tube.

Now, there is a continual tendency for the free electrons within the gas to combine with positive ions. Whenever this happens, light is produced. Or if an electron is not completely displaced, but is simply disturbed from it's normal position, to which it is caused to revert, light is likewise produced.

The action of the cathode is of special importance. It is necessary, in order to maintain the discharge, for the positive ions to strike the cathode with sufficient force to liberate electrons from it. This necessary force is established when a sufficient number of positive ions have accumulated in the region of the cathode to produce by their accumulation what is called a positive space charge. The accumulation continues automatically until this positive space charge becomes of such value that the difference of potential between it and the electrode is large enough to give to the positive ions a sufficiently high velocity to liberate electrons from the cathode when they strike. Thus the balance is obtained when just enough electrons are ejected from the cathode by those impacts of positive ions to keep the discharge going. Electrons thus liberated have, by virtue of the strong field, a very high velocity when they are close to the cathode, and consequently have a very strong ionization effect. The dark spaces occur where the velocity of the electrons is too high for recombination.

ELECTRICAL CHARACTERISTICS.

Due to the accumulation of positive ions near the cathode, the potential or voltage which is impressed across the tube is not uniformly distributed throughout its length, as it would be along a wire in which simple conduction takes place. In fact, there is a very large amount of potential difference near the cathode—that is, between the cathode itself and the negative glow. In the positive column the potential is uniformly distributed, and at the anode there is again a small rise in the voltage, due to a slight accumulation of negative charges there. Thus there are essentially three component parts to the distribution of potential or voltage along the neon tube:

(*a*) The cathode fall of potential, which has also been called the cathode drop, or electrode drop;
(*b*) The positive column gradient, which has also been called the positive column drop;
(*c*) The anode fall of potential, which has also been called the anode drop.

For our purposes, the anode drop, since it is constant and depends substantially upon the gas alone, is not of vital interest. The positive column drop is a simple factor and easily understood. The cathode fall of potential, however, is dependent upon many variables, and its value has a vital bearing upon the life and efficiency of the tube. Consequently it is of special interest to understand the factors which control its value.

For a given material the cathode fall of potential is of a constant minimum value, called the normal cathode fall of potential, so long as the negative glow does not completely encompass the surface of the electrode. When the negative glow just covers the surface of the electrode, as the current through the tube is increased, the positive space charge necessary to crowd additional positive ions on the electrode increases. This increase is very rapid as additional current is passed through the tube, and gives rise to abnormal cathode fall of potential. The value of the normal cathode fall of potential is independent of the pressure of the gas, but varies considerably with the material of the electrode, being relatively low, of the order of 50 volts for the alkali metals, as compared with the normal cathode fall of potential for the base metals, such as copper and iron, where the normal value is about 200 volts. The value of the current per unit of electrode area is called the electrode current density. The current density when the electrode drop is normal is called the normal current density, and, when the electrode drop is abnormal, the abnormal current density. The normal current density, however, varies quite substantially with the pressure of the gas employed, varying approximately as the square of the pressure. For instance, the portion of the electrode which is covered with negative glow (useful area of the electrode) at three millimeters pressure of gas for a given tube current, is about ten times as great as the area which would be thus covered at ten millimeters pressure with the same current.

It was observed early in the art, and has since been formulated into the so-called "Hehl's Law," that the current density is constant until the cathode is covered by the negative glow, and is called the "normal current density." It may also be stated in the reverse that the area of the negative glow entirely covers the cathode. Now when the cathode is entirely covered by the glow, and the current is further increased, there is no place for additional positive ions to go except to crowd on so that the current density at that point actually increases, and the current density may be said to become abnormal. In other words, abnormal current density is that which occurs with increase of current after the negative glow entirely covers the cathode.

Now there is a so-called critical point in this function and it occurs at the point where the negative glow entirely covers the cathode.

Current density in the neon tube and its concomitant, the area of the negative glow, are governed by three factors: (1) Pressure (2) Electrode material (3) Area of the electrode.

THE FUNCTION OF PRESSURE.

The function of pressure as controlling or regulating the current density and the area of negative glow has also been formulated into what is sometimes called the "Holm's Law," and it may be stated, that with change of pressure the normal current density changes as the square of the pressure; or it may be otherwise stated as, the area of a cathode glow for a given current varies inversely as the square of the pressure. We have seen that the cathode fall of potential for any given pressure is constant until the cathode is entirely covered by the glow, and thereafter the cathode fall of potential increases rapidly with the further increase of current. Also it may be stated that the cathode fall of potential is constant with any given pressure until the glow covers the cathode, and thereafter it increases or decreases with pressure. It follows, therefore, that the rise of cathode fall of potential from normal value to abnormal value may be produced either with increase of current with constant pressure, or by reduction of pressure with constant current. Change of pressure may therefore be compensated for by change of current, or vice versa, so that by changing either the pressure or the current, the cathode fall of potential may be kept constant for the selected pressure or current.

Because of Holm's Law, it follows that a change of pressure in any given ratio compensates for a change of current in a greater ratio—that is, approximately as the square. Therefore, for example, by doubling the pressure, one may practically quadruple the current used, without changing the cathode drop.

We have just observed that the critical point between normal and abnormal cathode fall of potential occurs when the negative glow completely encompasses the electrode. We have also seen that the change from normal to abnormal is regulated or controlled by pressure. It therefore obviously follows that this critical value, as well as any other value of current density, changes with a change of pressure, and that one can deliberately, by making adjustments of current and pressure, select any value of current density without changing the cathode drop.

SPUTTERING.

Associated with the fall of potential at the electrode is a phenomenon called sputtering, which is a form of vaporization of the metal of the electrode. The point of impact upon the electrode surface of the impacting positive ion becomes highly heated locally. From these infinitesimal heated spots local volatilization of the electrode material takes place, and the atoms of the metal thus chipped off from the electrode are deposited upon the glass walls adjacent to the electrode. In this film thus deposited a considerable amount of the neon gas within the tube is progressively included. The removal of the gas from the tube causes it eventually to become useless, and consequently considerable importance is attached to the factors which govern the rate of sputtering. These factors are three: (1) the material of which the electrode is made; (2) the value of the electrode drop; (3) the gas pressure within the tube. These are the elements which *directly* affect the rate of sputtering, disregarding for the moment their effect upon one another.

The direct effect of material depends upon its latent heat of vaporization—that is to say, its natural facility for vaporizing. The direct effect of the electrode drop is upon the velocity—that is, the energy of the impacting positive ions. Thus, if the electrode drop is high, the positive ions which strike the metal surface have greater energy and consequently produce greater heating and vaporization. The direct effect of the pressure controls the facility with which the atoms of the vaporized metal travel through the gas to the glass walls. If the pressure is sufficiently high, the sputtered particles of electrode material may never reach the glass wall, since they collide with so many atoms of gas on the way that they lose their velocity and are turned back to the electrode.

The effect upon one another of these variables is, however, of the greatest significance. Thus, the selection of the material itself governs, to a very large extent, the value of the electrode drop. Likewise, the effect of high gas pressure is not limited to its direct effect in depressing the sputtering, but likewise, from the point of view of current density, plays a very important part in the electrode drop. The current density selected must be of such a value that the electrode drop is low, and the material of the electrode and the pressure of the gas are the determining factors in the selection of this current density.

THE LIFE OF THE TUBE.

The life of the tube is ended when the pressure of the neon gas within it has been reduced by absorption to a point where under its specific conditions of operation, conduction through it can no longer take place. Thus, the life of the tube depends obviously upon the amount of gas present within it, to begin with, and the rate at which the gas is absorbed. Obviously, likewise, the conditions for maximum life are the maximum amount of gas which can be efficiently employed within the tube, and the minimum rate of absorption.

With respect to the amount of gas which may be used, there are two factors: the volume of gas in the tube, and the pressure of the gas. With neon signs, the volume of the tube is more or less fixed by factory practice, it being desirable to manufacture tubes of relatively small dimensions, so that they may be easily handled in installation and servicing. The pressure of the gas is therefore the only variable factor in this connection. In practice gas pressures of from 7½ millimeters to 24 millimeters are employed. The conditions for maximum operating efficiency (watts per candlepower) with respect to pressure are in the range of from 1 to 3 millimeters pressure. However, the sacrifice of efficiency in increasing the pressure to 24 or 25 millimeters is relatively small, whereas the benefits derived are very large. Consequently the practice is to employ pressures far in excess of the most efficient range.

Although the rate of absorption of the gas depends on other factors, they are of relatively small significance compared with the rate of absorption due to sputtering.

The conditions for minimum sputtering are therefore of special importance. They may be summarized as follows: (1) The selection of a material for the electrode whose normal cathode fall of potential is relatively low, and which has a relatively high latent heat of vaporization; (2) the employment of electrode areas with respect to the current to be used in the tube for the particular electrode material chosen, and the pressure of the gas to be employed, whereby the normal cathode fall of potential is not exceeded; (3) the selection of the highest efficient pressure in consideration of the use to which the tube is to be applied. If this use is to be in neon signs, as is the usual case, pressures as high sa 24 millimeters may be employed, whereby the electrode areas for any of the useful materials corresponding to less than one square decimeter per ampere may be employed without substantially affecting the normal cathode fall of potential.

THE EFFECT OF ELECTRODE MATERIAL ON THE LIFE OF THE TUBE.

We have already observed at various places that the character of the material in the electrode largely influences the life of the tube. For, instance, we have just seen that the difference in the voltage drop between the alkaline metals and the common metals in neon gas is of the order of 150 volts —that is, the normal cathode drop of alkaline metals such as cæsium, potassium, etc. is of the order of 50 volts, whereas the normal cathode drop for the base metals such as iron, copper, etc. is of the order of 200 volts. We know that the use of cæsium in the electrode definitely prolongs the life of the tube. In an experiment performed with a U-shaped neon tube with a copper button having an area of 1.5 square decimeters per ampere with 5½ millimeters pressure, the tube lasted 41 hours, when it failed because of hardening—that is, the gas was used up. The same tube with cæsium lasted 146 hours, when the seal broke. Thus the life of the tube was increased four times. It was seen, therefore, that the material of the electrode does have a more than appreciable effect upon the life of the tube.

THE EFFECT OF PRESSURE ON THE LIFE OF THE TUBE.

We have also seen that the effect of gas pressure is to provide not only additional volume but a distinct function in the operation of the tube.

An early experiment with a two-foot U-shaped tube 15 mm. in diameter, with an electrode area of 7½ square decimeters per ampere using from 2 to 15 mm. pressure was performed. The result was that the tube with 2 mm. pressure lasted 144 hours, and the tube with 15 mm. pressure, 11,427 hours. In other words, the life of the tube was increased by increasing the gas pressure in the order of the square of the pressure. In later similar experiments, results were somewhat better. It was determined that increase of pressure increased the life of the tube in the order of the cube.

Of course, the present use of the high pressure neon tube is a complete demonstration of the effect of pressure on the life of the tube. In these tubes a pressure of 24 mm. is maintained with an electrode of ordinary iron wire with an extremely small area. Such tubes have been shown to have a life exceeding 15,000 hours.

A NEW CYANIDE FURNACE.

BY

R. F. JAMES and GLENN COLEY,

Research Department,
The Detroit Edison Company.

The operation of electrically heated cyanide pots for steel hardening from a bath of molten cyanide has not always been satisfactory. The great objection has been the short and uncertain life of the heating elements which are made of a chrome-nickel alloy.

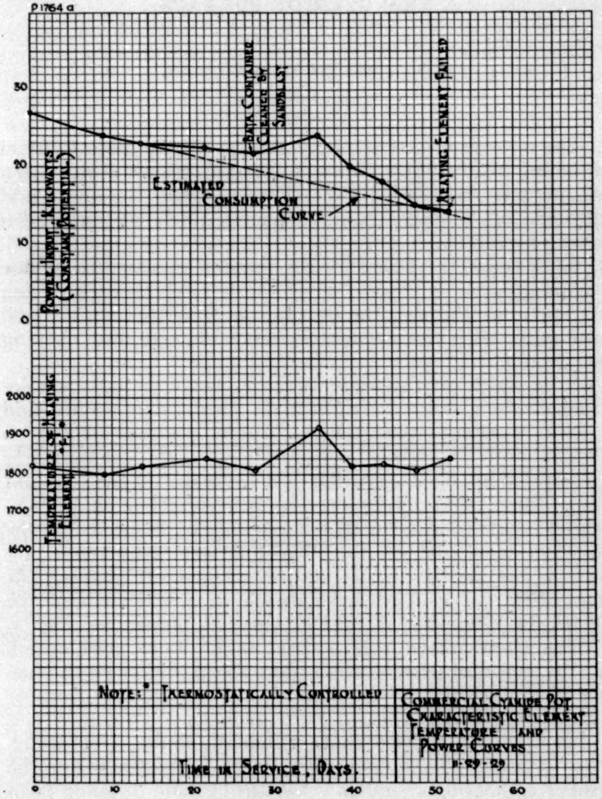
In all cases, the failure of the furnace appeared to be due to a progressive deterioration of the heating element, which was apparent through the development of "hot spots" and terminated with the element burning through and opening the circuit.

As a check on this deterioration, watthour meters were attached to a standard furnace in production service and periodic readings were taken. These readings showed a gradual drop in power consumption. This consequently necessitated a longer operating cycle to maintain the constant temperature in the furnace. In consideration of the decreased power consumption, it could only be deduced that the cross-sectional area of the elements was decreasing. By plotting the watthour meter readings and establishing the trend of the curve, it became possible to closely estimate the life of the element. A typical curve is shown on Fig. 1.

This phenomenon was noticed to be more pronounced, and the curve of deterioration more steep, the older the furnace or the greater the impregnation of the heating chamber walls with cyanide.

Investigation showed that, within the limits of economy, it was difficult to exclude cyanide or its components from the element or heating chamber. Molten cyanide dripping from the work as it was removed from the bath fell on the hot apron covering the furnace and leaked in through joints. Due to expansion and contraction in the circular pieces com-

FIG. 1.


P 1764 a
Bath Container Cleaned by Sandblast
Heating Element Failed
Power Input, Kilowatts (Constant Potential)
Estimated Consumption Curve
Temperature of Heating Element, °F.*
30
20
10
0
2000
1900
1800
1700
1600
Note: * Thermostatically Controlled
Commercial Cyanide Pot Characteristic Element Temperature and Power Curves
11-29-29
Time in Service, Days.
0
10
20
30
40
50
60

posing the top, it was practically impossible to make permanently tight seals. It was also found that molten cyanide or its components seeped through the metal of the bath container even though no flaws in the casting could be discerned. Examination of failed furnaces showed a "mossy" growth on the exterior walls of the container and deposits of what appeared to be cyanate on the floor of the element chamber under the container. Small piles of metallic scale or dust were found around the elements.

From these indications it was evident that the element deterioration was associated with the presence of cyanide or its components. In the fall of 1928 an investigation was made to determine the effects of cyanide on chrome-nickel alloy.

A piece of chrome-nickel wire was supported in a closed hood which covered a sand bath containing a crucible of molten sodium cyanide. The wire was heated by the passage of a current and watthour meter readings were taken. The set-up was run during the day and allowed to cool at night, thus simulating the work cycle of production furnaces. Plotting of readings showed the same type of curve as was obtained from the production furnace. A natural acceleration took place due to the increased concentration of cyanide. These curves are shown by the solid lines in Fig. 2. The dotted lines of Fig, 2 show readings taken on a similar piece of wire heated in air. In this instance no cyanide was present and the typical deterioration did not take place. It was also found that the rate of element deterioration in the presence of cyanide increased with an increase in element temperature. Approximately 1650° F. marked the economic maximum temperature.

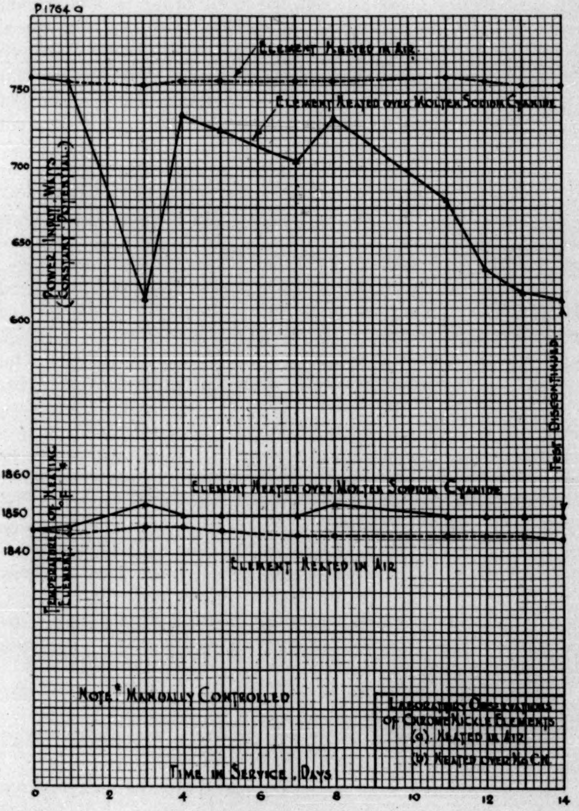
From field observations and laboratory experiments the following conclusions were drawn:

1. Cyanide or its components have a deleterious effect upon chrome-nickel alloys.

2. The reaction between cyanide and chrome-nickel alloys increases rapidly with an increase in temperature, and approximately 1650° F. is the maximum safe temperature for economic operation.

3. It is not economically practical to exclude cyanide or its components from the element chamber.

FIG. 2.


P1764 a
Element Heated in Air
Element Heated over Molten Sodium Cyanide
750
700
650
600
Power Input, Watts (Constant Potential.)
Test Discontinued
1860
1850
1840
Temperature of Heating Element, °F. *
Element Heated over Molten Sodium Cyanide
Element Heated in Air
Note * Manually Controlled
Laboratory Observations of Chrome Nickle Elements
(a). Heated in Air
(b) Heated over Na CN
Time in Service, Days
0
2
4
6
8
10
12
14

4. The deterioration of chrome-nickel heating elements heated in air is exceedingly slow (at temperatures below 1800–2000° F.).

Based upon these conclusions an hypothesis was propounded to explain the deterioration of the heating elements.

When cool, the heating elements are in a normal room atmosphere. As the furnace is brought up to temperature, the atmosphere in the element chamber gradually changes from normal to one containing cyanide or its components. This is due to the volatilization of the cyanide that has entered the element chamber by one of the ways previously discussed.

The exact reaction of either sodium or potassium cyanide with chrome-nickel cannot be definitely stated. Normally the cyanides when heated simply fuse, except when in the presence of air they take oxygen from the air and become the relatively inactive cyanates. Both sodium and potassium cyanide are very powerful reducing agents and as such might attack the coating of protective oxide usually found on chrome-nickel elements. However, both of these cyanides readily form complex salts when heated with metals and it is probably these salts that are found around the elements in failed furnaces.

When the furnace is at heat, a condition exists where the concentration of cyanide is at a maximum and atmospheric air at a minimum. This lack of oxygen permits the cyanide to exist as such without the change to cyanate. At this period the elements are hottest and conditions are at optimum for rapid destructive reaction. The scale or dust caused by reduction of oxide is formed as a hard shell on the elements at this time.

As the furnace cools down, the outside air enters the element chamber and tends to neutralize the chamber atmosphere by converting the cyanides to inactive cyanates. As the elements cool they contract and the partially reduced scale flakes off leaving the virgin metal exposed to a repetition of the attack of alternate oxidation and reduction during the next heat. This cycle tends to decrease the cross-sectional area of the heating elements and constitutes the deterioration.

On the strength of this hypothesis, it is evident that the maintenance of an oxidizing atmosphere in the element chamber at all times is essential to the preservation of the elements.

With these ideas in mind, an experimental furnace was designed and built by the Research Laboratory of The Detroit Edison Company and placed in the plant of The Gemmer Manufacturing Company of Detroit, for a production test.

Figure 3 shows a sectional view of the furnace as constructed. At the bottom of the element chamber and in the center directly below the cyanide container is placed the outlet of the air intake pipe. This opening is obstructed by a baffle so arranged as to assist natural convection in directing the air flow against the elements during the heating period and against the container during the cooling period. In this manner the element chamber, during the hot cycle, is swept with clean air at the critical points.

To permit natural draft to accomplish the work just outlined, offtakes opening into the highest point of the combustion chamber are led off radially into a bustle pipe which in turn goes to a vent discharging to outdoors above the roof. The amount of air passing through the combustion chamber is controlled by a damper in the vent pipe.

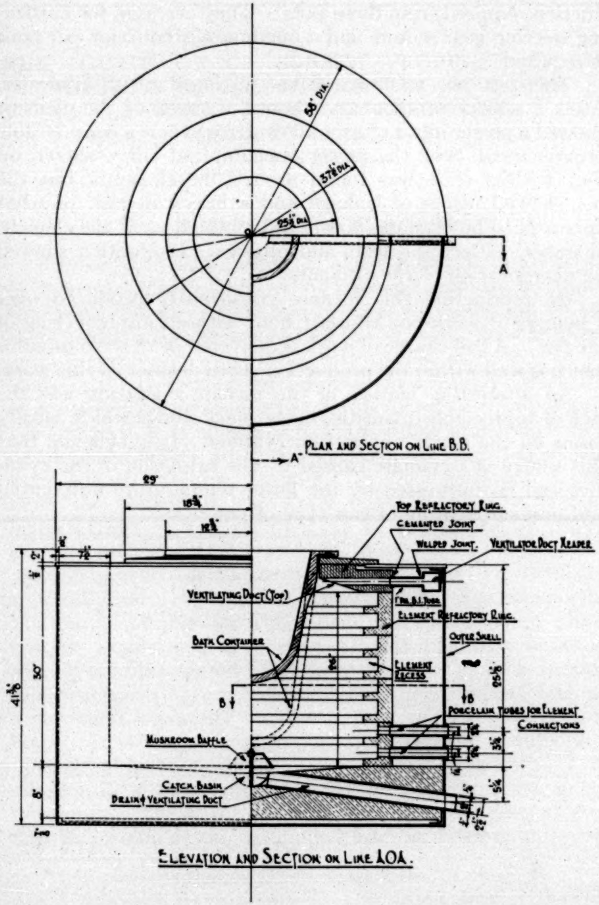
This circulation of air accomplishes the dual purpose of oxidizing any fumes that get into the chamber and tends to maintain an even temperature due to turbulence.

The distance between the outside of the container wall and the heating element was increased over the standard practice in order to hold additional element capacity. This was done in order to lower the element temperature without decreasing the total heating capacity. This increase in the volume of the element chamber also tended to cut down the heat loss through the ventilating stack because of the lower thermal head obtained.

The heavy wall insulation permits a greater degree of comfort to the operator. During operation with element temperatures at 1600° F., no great discomfort is felt when standing directly against the furnace exterior.

As stated, one of these furnaces was placed in the plant of The Gemmer Manufacturing Company of Detroit for a life test under operating conditions. This service was as

FIG. 3.


58" DIA.
37½" DIA
25½" DIA
A
PLAN AND SECTION ON LINE B.B.
A
29"
18¾"
12¾"
7½"
41⅞"
30"
8"
25⅝"
3⅝"
5¼"
TOP REFRACTORY RING.
CEMENTED JOINT
WELDED JOINT.
VENTILATOR DUCT HEADER
VENTILATING DUCT (TOP)
ELEMENT REFRACTORY RING.
OUTER SHELL
BATH CONTAINER
ELEMENT RECESS
B
B
PORCELAIN TUBES FOR ELEMENT CONNECTIONS
MUSHROOM BAFFLE
CATCH BASIN
DRAIN & VENTILATING DUCT
ELEVATION AND SECTION ON LINE AOA.

severe as any cyanide pot service because of the heavy production required from these pots. They are used for hardening steering gear sectors and a maximum production per hour is required.

This test pot as designed has an input of 43 kilowatts. After a service of 1800 work hours, a check of the element showed a power input of 42.5 kilowatts which is a considerable improvement over the power consumption curve shown on Fig. 1. No scale was found around the elements, but the pot showed traces of leakage and a heavy deposit of what appeared to be cyanates was found on the floor of the element chamber. Electrical tests and physical examination showed no deterioration of the elements.

On production this furnace consistently produced over 4 pounds of work per kilowatt hour without any covering of the pot. A full charge of work is delivered in 18 to 20 minutes which is well within the production speed desired on this work.

An interesting feature of the furnace operation was the lack of appreciable quantities of the black sludge which usually forms on the surface of molten cyanide. It is believed that this sludge is a cyanate caused by the oxidation of the cyanides and is suppressed by the lower temperature differential and uniform heating of this type of pot.

THE DEPRESSION OF DENSITY PRODUCED BY THE PRESENCE OF BROMIDE IN THE DEVELOPER OF PHOTOGRAPHIC EMULSIONS EXPOSED TO LIGHT AND TO X-RAYS.

BY

A. P. H. TRIVELLI AND E. C. JENSEN.*

Introduction.—The Herschel effect is the diminution of a developable density produced by a second exposure to light of long wave-length. Potassium bromide is a sensitizer for this effect and is also able to produce the Herschel effect in photographic emulsions which otherwise do not show it. In the study of the Herschel effect information concerning the action of potassium bromide in developers is therefore of importance. For instance, it is necessary to know which grains and which developable nuclei are most sensitive to radiation of long wave-length. Soluble bromides in the developer depress most the density of the lower exposures. In a previous investigation of fog removal in development, we[1] found that a suitable concentration of 6-nitrobenziminazole in a paraminophenol developer will remove the fog with the smallest density depression. This developer is at the moment the most suitable for theoretical investigations of photographic emulsions. But even in this case the action of soluble bromide cannot be entirely ignored. Soluble bromide is a reaction product formed during development and will accumulate especially in the depths of the photographic layer. It is therefore of importance from the standpoint of photographic theory that more should be known of the density depression produced by soluble bromide in the developer. The best method would be grain size analysis, and this method will be applied later in a separate investigation. At present the mathematical treatment of the distribution of sensitivity specks, exposure, and developable centers in relation to the size-frequency curves of the photographic emulsion is too complicated for light exposures to give data which can be tested quantitatively with the observations. Quantitatively determined data can, however, be brought in connection with the latent image theory of the growing sensitivity speck.

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* Communication No. 452 from the Kodak Research Laboratories.

[1] Trivelli, A. P. H., and Jensen, E. C.: Antifogging Agents in Developers, J. FRANKLIN INST., 210: 287, September, 1930.

Motion picture positive and negative film was used in the investigation, and the depression of density produced by the presence of soluble bromide in the developer was compared in relation to equal densities for daylight and x-ray exposures in spite of the fact that their photometric equivalent differs slightly.

Exposure.—The light exposures were made with a non-intermittent sensitometer of 20 steps $\sqrt{2}$ ratio exposure. The light intensity was kept constant and the time of exposure was varied. The maximum time of exposure was 724 seconds. The light source was a 500 candle power standard monoplane tungsten filament lamp operated at 89 volts and 4.05 amperes to give a color temperature of 2900° K. The light intensity was kept constant by a voltage regulator, which kept the voltage constant to within one volt, corresponding to a maximum deviation of 6 per cent. of the light intensity of the actinic part of the spectrum of the light source. The photographic film was placed at a distance of 99.1 cm. from the diaphragm with opal glass diffusion screen. This diaphragm gives a light intensity of 0.0347 mc. on the photographic plate. No filters were used.

The x-ray exposures were made by Mr. R. B. Wilsey of the x-ray department of these laboratories. The ratio of exposures was in power of 2 steps. A water cooled metallic tube with tungsten target was used. The tube voltage was 85 kv. by 4 ma. The film was wrapped in black paper in an Eastman x-ray exposure holder and exposed at a target distance of 76.5 cm.

Development.—Development was effected in a bath at 20° ± 0.1° C. controlled by thermostat with brush according to W. Clark.[2] The following two developers were used:

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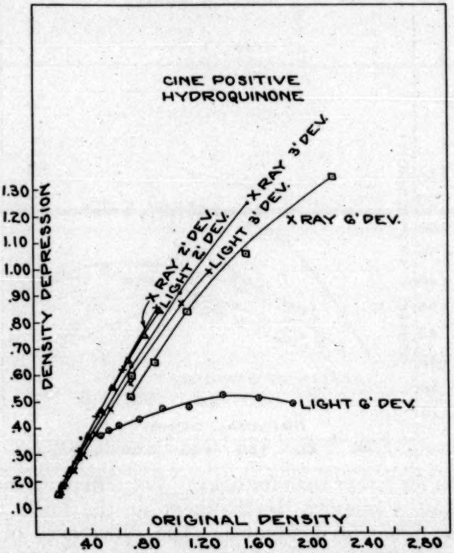
[2] Clark, W.: Standard Development, *Phot. J.*, **49**: 76, February, 1925.

I.	Pyrogallol	3.15	gm.
	Sodium sulfite (anh.)	50.	
	Sodium carbonate	50.	
	Water to make	1.	liter
II.	Hydroquinone	5.5	gm.
	Sodium sulfite (anh.)	50.	
	Sodium carbonate	50.	
	Water to make	1.	liter

The sulfur dioxide content of the sodium sulfite was determined analytically and the actual amount calculated for an equivalent of 100 per cent. pure salt. The results with these developers were compared with the results with the same developers to which was added 5 gm. potassium bromide per liter developer.

FIG. 1.

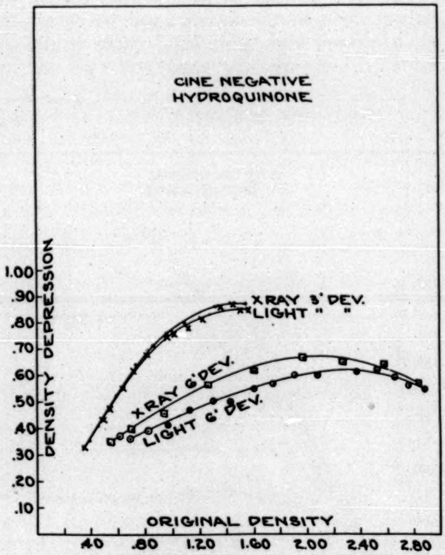


Densities were read on a Martens densitometer.

Treatment of Data.—Every exposure was repeated three times and the data obtained were averaged without any smoothing of the curves. The density depression was expressed by the density difference of the same exposure after development without and with potassium bromide.

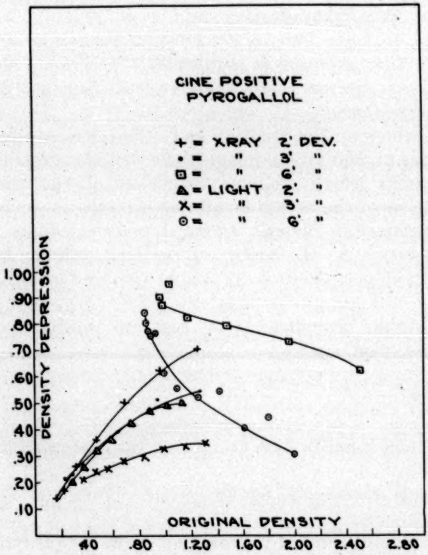
Discussion of Data.—In Fig. 1 are given the data obtained for 2, 3 and 6 minutes hydroquinone development using motion picture positive film. We notice a greater density depression for x-rays than for light. The difference disappears with 2 and 3 minutes development at the lower densities where fog removal dominates. The differences of density depression between light and x-ray exposures increases with higher densities and with longer times of development.

FIG. 2.



In Fig. 2 are given the data obtained for 3 and 6 minutes hydroquinone development using motion picture negative film. Again x-ray exposures show greater density depression than light exposures, and again the differences increase with increasing time of development. These differences increase also with higher densities with maximum at about D = 1.60, which seems to point to the fact that with longer exposures the conditions for development become more equal for x-rays and for light exposures and we may expect that this condition will be sooner established with emulsions of high sensitivity than with those of low sensitivity.

FIG. 3.



In Fig. 3 are plotted the data for 2, 3 and 6 minutes pyrogallol development using motion picture positive film. Again the x-ray density depression is greater than the light density depression. In Fig. 4 are plotted the data for 3 and 6 minutes pyrogallol development using motion picture negative film.

For 3 minutes development the light exposure has more density depression than the x-ray exposure.

Conclusions.—We conclude from these experiments that if,

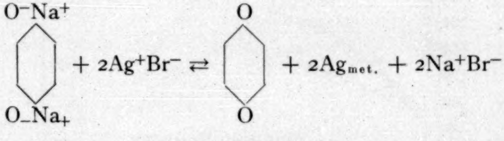
(I) *at shorter times of development, the density depression for light exposures is greater than the density depression for x-ray exposures, this difference will diminish with longer times of development, and may reverse with still longer times of development, so that x-ray exposures show greater density depression than light exposures;* and

(II) if, *at shorter times of development, the density depression for the daylight exposure is smaller than the density depression for the x-ray exposure, this difference will increase with longer times of development.*

This brings up the question as to the relationship of these conclusions to the latent image theory of the growing sensitivity speck, which requires extension of the theoretical investigation of the action of soluble bromide in developers.

Physiochemical Theories of the Action of Soluble Bromide in Developers.—A. H. Nietz[3] states that soluble bromides may affect development in probably two and possibly three ways:

(1) Soluble bromides, being reaction products of a reversible reaction, such as



lower the driving force of the reaction in the forward direction. This view was first presented by H. E. Armstrong.[4]

(2) The soluble bromide depresses the concentration of silver ions by the action of the common anion, Br^-, a theory first brought forward by R. Abegg.[5]

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[3] Nietz, A. H.: Theory of Development, Monograph no. 2 from the Kodak Research Laboratories, Rochester, N. Y., Eastman Kodak Co., 1922, p. 221.

[4] Armstrong, H. E.: Chemical Changes Attending Photographic Operations, I, *Brit. J. Phot.*, **39**: 276, 1892.

[5] Abegg, R.: Action of Bromide in Developers, *Eder's Jahrbuch*, **18**: 65, 1904.

(3) The bromide may have a specific action other than that mentioned in (2). Concerning such a possibility we have little knowledge, but various phenomena occurring in high concentrations of bromide indicate effects quite different from those described in (1) and (2).

The action mentioned under (1) explains changes in the reaction velocity of the developer, especially with prolonged development and in the depth of the photographic layer where the soluble bromide concentration is increased. It can scarcely have any influence at the lower exposures, where the density depression expressed as per cent. is the highest, decreasing in general toward the higher densities. This action will not be considered, therefore, in the present investigation of the density depression.

What has been said applies also to the action mentioned in (3). If the greatest density depression is at the lower exposures, an action which shows an effect only at higher concentrations can be ignored because of the low concentrations of soluble bromide considered in this investigation.

It seems to us that the most important action is that given by R. Abegg. Previously, G. Bredig[6] found that potassium bromide in photographic developers reduces its reduction potential. R. Abegg, applying physicochemical laws, considered development as consisting of two simultaneous processes: oxidation of the developer $-{}^{-}R^{-} \rightarrow R^{-}$, and reduction of the silver ion $- Ag^{+} \rightarrow Ag_{met.}$, each tending to reach equilibrium as defined by fixed values of the ratios $\left[\frac{\bar{R}}{R_{-}}\right]$ and $\left[\frac{Ag^{+}}{Ag_{met.}}\right]$. For a "strong" developer, the value of the equilibrium ratio for the reaction $Ag^{+} \rightarrow Ag_{met.}$ is greater than for a "weak" one; that is, the "stronger" developer can reduce silver from a solution weaker in silver ions (richer in bromine ions). The bromide susceptibility is therefore a measure of the developing potential of the reducing ion. The physical chemistry of density depression by soluble bromides in the developer has been worked out further in terms of both reversibility and ionic depression by S. E.

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[6] Bredig, G.: Electromotor Scale of Photographic Developers, *Eder's Jahrbuch*, 9: 19, 1895.

Sheppard.[7] It was the early part of this work[8] which developed a method of measuring developer reduction potential subsequently improved by A. H. Nietz.[3]

The Speck Growth Theory of the Latent Image Applied to the Action of Soluble Bromide in Developers.—In 1925 one of the authors, with Sheppard and Loveland,[9] proposed the concentration speck theory of the latent image. According to this theory the light action on photographic emulsions consists of the accumulation of photochemically liberated silver atoms around a preëxisting speck on the surface of the silver halide grains so that at a certain size of the nucleus developability is introduced.

The basis of the speck theory of development has been suggested before. For instance, The Svedberg, O. H. Schunk and H. Anderson[10] thought that developable nuclei were formed only when light quanta of sufficient energy struck the grain and were absorbed within a certain minimum area. On the basis of Zsigmondy's investigations[11] of gold deposition on colloidal gold particles, H. J. Vogler and W. Clark[12] estimated that about 300 silver atoms are necessary to form a developable center.

If we call a "strong" developer in the sense of Bredig a developer with a high reduction potential, such as monomethylparaminophenol sulfate, and if we call a "weak" developer a developer with a low reduction potential, such as ferrous citrate, then for a short time after development with these two developers we observe that the "strong" developer is able to develop short exposures, which are not developed by "weak" developers. From the standpoint of the speck growth theory of the latent image this means that "strong" developers are more able to induce developability in specks of smaller size than "weak" developers.

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[7] Sheppard, S. E.: *J. Chem. Soc.*, **87** (2): 1311, 1905; ibid., **89** (1): 530, 1906; *Z. wiss. Phot.*, 3: 97, 1905; *Z. Chem. Ind. Koll.*, **5**: 43, 1909; Tr. Amer. Electrochem. Soc., **39**: 429, 1921; *Phot. Korr.*, **59**: 76, 1922; J. FRANKLIN INST., **195**: 211, 1923; ibid., **198**: 333, 1924; Tr. Faraday Soc., **19**: 355, 1923.

[8] Sheppard, S. E., and Mees, C. E. K.: Theory of the Photographic Process, Longmans, Green & Co., 1907.

[9] Sheppard, S. E., Trivelli, A. P. H., and Loveland, R. P.: Studies in Photographic Sensitivity, VI, The Formation of the Latent Image, J. FRANKLIN INST., **200**: 51, July, 1925.

[10] Svedberg, The, Schunk, O. H., and Anderson, H.: Relation between Exposure and Number of Developable Centers, *Phot. J.*, **48**: 272, June, 1924.

[11] Zsigmondy, in Darstellung kolloider Goldlösungen nach dem Keimverfahren, by J. Reitstötter, *Kolloid-Chem. Beih.*, **9**: 222, 1917–18.

[12] Vogler, H. J., and Clark, W.: Latent Image and Development, *Brit. J. Phot.*, **74**: 670, Nov. 11, 1927.

This is also observable if we add a certain amount of soluble bromide to a developer. According to G. Bredig and R. Abegg the soluble bromide "weakens" the developer. From the standpoint of the speck growth theory of the latent image this means that soluble bromide in the developer shifts the lower limit of the size of developable nuclei to larger sizes. In 1905 Sheppard [13] had already explained the shift produced by soluble bromide in terms of the activity of development and this is also in agreement with the observation that the greatest action of soluble bromides is noticeable at the lower exposures which contain fog and smaller developable centers.

In an investigation on the action of x-rays on photographic emulsions, S. E. Sheppard and one of us [14] found that the silver halide grains are, over their surface, all equally sensitive to x-rays. The formation of a developable center takes place independently from a preëxisting sensitivity speck. W. Nernst and W. Noddack [15] computed that an x-ray quantum of about 0.5 angstrom liberates about 1000 silver atoms in a silver halide grain. Therefore every x-ray quantum of such a wave-length makes a grain developable. A photographic emulsion after exposure to such "monochromatic" x-rays would contain a distribution of developable specks of equal size. The inference drawn from these data have been worked out and experimentally tested by L. Silberstein and one of us,[16] so that we are justified in using these results as a basis for our further investigations.

The effect of daylight exposure on a photographic emulsion is quite different. Different wave-lengths in blue, violet and near ultraviolet act on sensitivity specks of different sizes. The result is a very complicated probability distribution of developable centers.

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[13] Sheppard, S. E.: *J. Chem. Soc.*, **87**: 1311, 1905.

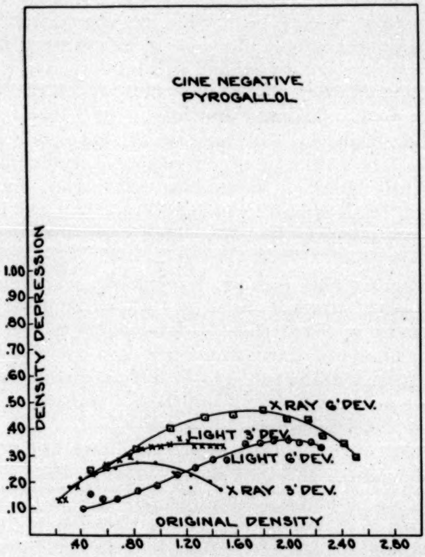
[14] Sheppard, S. E., and Trivelli, A. P. H.: Sensitivity of Photographic Emulsions in Relation to Quantum Energy in Exposure, *Phot. J.*, **50**: 505, Nov. 1926.

[15] Nernst, W., and Noddack, W.: Theory of Photochemical Processes, *Sitz. d. preuss. Akad. Wiss.*, 1923, p. 110.

[16] Silberstein, L., and Trivelli, A. P. H.: Theory of X-ray Exposures on Photographic Emulsions, *Phil. Mag.*, Supp., **9**: 787, May, 1930.

From these considerations we can conclude, that with small amounts of soluble bromide in the developer we may expect that the density depression will be smaller with x-ray exposures than with daylight exposures. It is necessary to consider the concentration of potassium bromide because with large amounts of soluble bromide the large x-ray centers may fall below the limit of developability. The quantitative data given in Figs. 1, 2, 3 and 4 are not, however, always in agreement with such a conclusion. Two other factors must be taken into consideration to explain these deviations:

FIG. 4.



(1) The applied x-ray radiation is not monochromatic. It consists of a continuous spectrum of different wave-

lengths in which the K radiation of tungsten appears with higher intensity. The absorption lines of silver and bromine lie near this K radiation. The developable centers of the x-ray exposure therefore consist of centers of different sizes of which the sizes produced by the wave-lengths of the absorption lines of silver and bromine are dominant. X-ray exposures therefore produce a number of smaller developable centers which become inactive in a developer containing soluble bromide. This will not make the density depression for light exposures greater than for x-rays but will diminish the differences which were expected previously.

(2) As is shown in Fig. 5, representing a cross section of motion picture negative film, the daylight latent image is distributed in the photographic layer so that its highest concentration lies near the free surface of the layer. In all the sections given in Figs. 5, 6 and 7 the upper surface is the free surface and the lower surface is lying in touch with the support. Fig. 6 shows the x-ray latent image distributed through the whole photographic layer. This means that in the deeper layer near the support the x-ray exposures produce a higher concentration of developable specks than light exposures if we compare equal densities of development.

The developer penetrating an exposed photographic emulsion starts development at the free surface forming soluble bromide as one of its reaction products. With deeper penetration the concentration of soluble bromide will increase, causing greater density depression. This is noticeable by comparing the sections of Figs. 6 and 7 with each other. Both have received the same x-ray exposures. Figure 6 represents a section with the density $D = 0.48$ and Fig. 7 is a section of the same film and the same exposure with the density $D = 0.25$. The film of Fig. 6 was developed in a plain pyrogallol developer, as given earlier in this paper without addition of soluble bromide, and the film of Fig. 7 was developed in the same developer with the addition of 5 gm. potassium bromide per liter developer. In both cases, the time of development was 6 minutes at $20° C. \pm 0.1°$, thermostatically controlled. This is only one case of many we have observed. We may state that density depression is greater in the deeper parts of a photographic layer than near the free surface, and whereas the x-ray density is built up out of silver grains, which are more concentrated in the deeper layers than light exposures give, we may expect that x-ray densities are more depressed than the corresponding light densities.

FIG. 5.

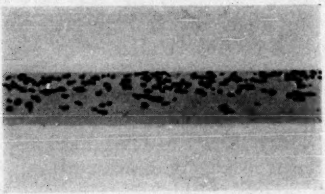


FIG. 6.

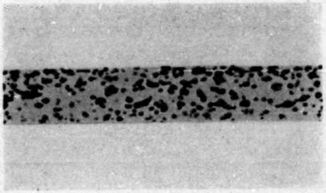
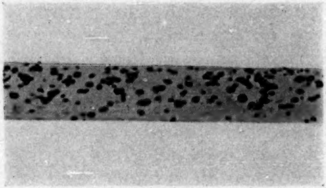


FIG. 7.



Film sections.
Thickness 2 μ.
420 × enlarged.

We conclude that there are two depression factors to be distinguished:

(*a*) The difference in sizes of developable centers formed by exposure will, with soluble bromide in the developer, give a greater density depression for light than for x-ray exposures.

(*b*) The distribution of the developable centers throughout the thickness of the photographic layer will give, for light, a smaller density depression with soluble bromide in the developer than for x-ray exposures.

The shorter the time of development, the nearer will the developed image be to the free surface of the photographic layer. The difference (*b*) will diminish with shorter times of development and the difference (*a*) will become more pronounced. This leads immediately to the two rules (I) and (II) which were formulated from direct observations. It is very probable that both conclusions hold coincidently and that it is only a question of shorter development that, in all cases, light exposures show a greater density depression with bromide in the developer than do the x-ray exposures with a tungsten target in Coolidge tubes.

Summary.—The density depressions of soluble bromide in the developer were determined with two different emulsions for light and for x-ray exposures with hydroquinone and with pyrogallol developer. Abegg's theory of the action of soluble bromide in the developer was the best explanation of the obtained results. This theory was connected with the speck growth theory of the latent image and the obtained results were explained on the basis of the size and the distribution of the specks.

Visible, Threadlike Beams of Electrons. E. BRÜCHE AND W. ENDE. (*Zeit. für Physik*, Vol. 64, page 186.) A beam of electrons a meter in length and having a cross-section of only one fourth of a square millimeter has been obtained. Though the details of its production are not furnished it is said to depend upon the presence of gas at a definite low pressure. The volume charge in the path of the electrons due to their passage keeps them from spreading out into a cone.

This long thin beam has interesting properties. Directed into the field of a horse-shoe magnet so that it moves in the plane between the poles that cuts all the lines of force at right angles it is deflected by the field but continues in this plane. A photograph shows the beam bent into a loop. Since the radius of curvature of such a deflected beam is inversely proportional to the field strength, by a mere inspection of the photograph it is possible to select the point of greatest strength. If the beam be sent vertically upward, the magnetic field of the earth deflects it toward the east. A photograph of this is reproduced, the bent line having a radius of curvature of 270 cm. Herein lies the possibility of using the beam as a magnetometer and as a compass. If the beam be sent into a uniform magnetic field oblique to the lines of force, it describes a helix winding around the lines. In the field of the earth the particular electrons used moved along a screw path of 80 cm. diameter and 590 cm. pitch. A photograph is shown in which in a powerful field the beam was bent into a form somewhat resembling a pair of pliers. Thus it becomes possible to reproduce in experiment Störmer's explanation of the aurora. The flexibility of the beam is due to the small velocity of the constituent electrons. G. F. S.

PRIMER TESTING SET.

BY

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SUMMARY.

This testing set is an "unbalanced" Wheatstone bridge for measuring the resistance of cannon primers. It is arranged to make its use perfectly safe on both lock and case primers. Some primers that tested as "good" on a Wheatstone bridge show a high or variable resistance on this testing set due to the lower current that is caused to flow through the primer bridge.

PRIMER TESTING SET.

The need of a portable primer testing set is evidenced in attempts at measuring primers by Wheatstone bridges and by head phone test sets. Primers have been exploded by both these devices while under test. Hence a set that will assure safety while measuring the resistance is extremely desirable.

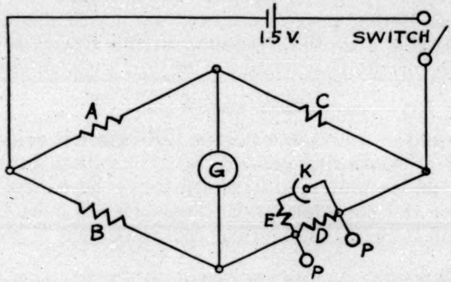
For this purpose an "unbalanced" Wheatstone bridge has been devised. It is readily portable and rugged. The galvanometer used is of the double-pivot type with fair sensitivity and damping and capable of a high overload continuously. Cushion springs at either end of the needle swing prevents damage to it. Besides these features of ruggedness, the bridge elements are enclosed in a sealed compartment separated from the No. 6 dry cell which is accessible for replacement. The resistors are so protected as to practically eliminate any chance of injury unless more than the prescribed 1.5 volts be deliberately applied. Under working conditions less than 0.05 ampere flows through the "X" arm of bridge. Of this amount, considering a "0.55-ohm" primer, less than 0.032 ampere can pass through the primer bridge.

The circuit is that of a Wheatstone bridge with a shunt resistor "D" in the "X" arm. The values of resistance of the various arms are:

"A"	31 ohms
"B"	30 ohms
"C"	0.47 ohm
"D"	1 ohm
"E"	0.04 ohm
"G"	25 ohms

The ratios of these arms throw the bridge out of balance until a normal primer is inserted in the clip "K" or at "PP." Then the galvanometer "G" deflects toward the left to the normal scale position marked "GOOD" on the dial. If a short-circuited primer is inserted the needle deflects to the extreme left; if an open-circuited one, it remains at the extreme right. Intermediate values lie in the positions marked "HIGH" and "LOW." A lead having 0.04-ohm resistance is provided for attachment to the binding posts "PP." This is intended for testing case primers, either separately or in cases. Compensator "E" corrects in clip "K" circuit for the resistance of this lead.

FIG. 1.



Two test resistors are furnished with the set, one has the resistance corresponding to the lower limit of a good primer, while the other has that corresponding to the upper limit. These are intended for testing needle position of the galvanometer by inserting in clip "K." Adjustment can then be made to suit. This may need to be done as the dry cell becomes weaker or when it is replaced.

It has been stated above that only about 0.03 ampere normally passes through the primer when tested in this set. Since the minimum firing current is more than ten times this amount, there is evidently no chance of firing, especially since the heating effect is proportional to the square of the current. This condition gives a factor of safety of a hundred to one. Moreover, the shunt resistor "D" prevents any chance of firing a primer by means of a spark jumping a gap within the primer, or by heating a reduced cross-sectional area of the primer bridge wire.

Experiments on this set show that in some cases where a regular Wheatstone bridge indicates a good primer, this set indicates one with high or variable resistance. This is due to the condition that the primer has the full voltage of the Wheatstone bridge impressed breaking down the high resistance and causing an appreciable current to flow. On the testing set this same primer, being shunted by the resistor "D," has only the potential drop in "D" impressed upon it.

This set has been tested in service and has proved thoroughly reliable and safe.

On Changes of Rock Temperatures and Irregularities of the Earth's Rotation. R. W. Wrigley. (*Proc. Royal Soc. Edinburgh*, Vol. L, Pt. II.) From 1837 to the present time readings of deep rock temperatures have been taken by means of four thermometers sunk in the rock of Calton Hill originally at depths of 25.6, 12.8 6.4 and 3.2 feet. They were installed by Prof. James Forbes. They had cylindrical bulbs 6 to 8 inches long and 1½ to 2½ in diameter, connected by capillary tubes to the level of the ground, where they enlarged into tubes having degrees of suitable length. Alcohol was the liquid used. "The thermometer at depth 12.8 ft. was broken by frost in 1861, but the readings of the remaining three continued without interruption till the year 1876, when a Portuguese sailor from a ship in Leith scaled the Observatory wall one night and wantonly destroyed all the thermometers and their wooden shelter." As soon as possible a new set of similar design was installed and readings were resumed. The depths of the new instruments were 250, 125, 50 and 25 inches respectively. One was broken in 1906 but the others were read regularly for 50 years. Readings of the first set were used by Prof. Forbes and Lord Kelvin in studies of rock conductivity and of the cooling of the earth.

In the period from 1838 to 1876 the highest average annual temperature of Edinburgh was 49.6° and the lowest 44.3°: for the thermometer at depth of 6.4 ft. the highest and lowest mean annual temperatures were 47.71° and 45.39°; for the instrument buried 25.6 ft. they were 47.98° and 46.16°. Thus the ranges for air and the two thermometers were respectively 5.3°, 2.32° and 1.82°.

The author treats the observations in such a way as to eliminate the changes in surface temperature, and from the residuals draws the conclusion that the temperature of the earth's crust was falling up to 1890 at which time it began to rise. It has continued rising for 30 years. This variation is confirmed by similar observations made at Greenwich. In Ernest W. Brown's tables of lunar motion there is included in the discrepancy between theory and the results of observation a "minor fluctuation" which is explained by the assumption of changes in the rate of the earth's rotation. When this minor fluctuation is plotted for the same years for which the temperature residuals were determined it is seen that its curve and theirs are closely parallel. This agreement seems to indicate that the surface of the earth's crust is hottest when the rate of rotation of the earth, after having been slower than usual, begins to increase.

G. F. S.

DYNAMICAL ANALYSIS OF MACHINES.*

BY

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ANALYSIS OF MECHANISMS SUBJECTED TO A COMMON ROTATION.

In a large class of machines we have mechanisms subjected to a common rotation angular velocity $\dot{\psi}$ and the configuration relative to the revolving axis defined by some coördinate θ. The governor mechanism previously discussed belongs to such a category. Other examples are the flywheel governor where the axis is horizontal.

Let A = the inertia coefficient with respect to the coördinate θ,
B = the inertia coefficient about the spindle or axis of rotation,
V = the potential energy including the action of gravity springs, etc.,
$F = \frac{1}{2}k\dot{\theta}^2$ = the damping or friction function of the mechanism,
Φ = the torque about the axis of rotation,
θ = the configuration coördinate of the mechanism with respect to the rotating frame,
r = distance from the axis to any mass m,
z = axial distance to any mass m,
ψ = angular coördinate of the rotating frame.

The inertia coefficients A and B are in general functions of the coördinate θ. That is,

$$A = \sum m\left(\left(\frac{\partial r}{\partial \theta}\right)^2 + \left(\frac{\partial z}{\partial \theta}\right)^2\right), \qquad B = \sum mr^2,$$

where r is a function of θ.

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* Extension of a portion of a dissertation for the degree of doctor of philosophy submitted to Clark University, 1928.

Continued from p. 242, vol. 211, February, 1931.

The kinetic energy has the form

$$T = \tfrac{1}{2}A\dot{\theta}^2 + \tfrac{1}{2}B\dot{\psi}^2$$

and the potential function is a function of the coördinate θ.

The torque acting on the system about the spindle axis is

$$\Phi = \frac{d(B\dot{\psi})}{dt} = B\ddot{\psi} + \dot{\psi}\frac{dB}{dt}$$

$$= B\ddot{\psi} + \frac{\partial B}{\partial \theta}\dot{\theta}\dot{\psi}.$$

The equation of energy is, therefore,

$$\Phi\dot{\psi} = \frac{d(T + V)}{dt} + \frac{dF}{d\dot{\theta}}\dot{\theta}.$$

Now the work of the torque Φ is

$$\Phi\dot{\psi} = B\ddot{\psi}\dot{\psi} + \frac{\partial B}{\partial \theta}\dot{\psi}^2\dot{\theta},$$

so that substituting in the equation of energy we have

$$A\ddot{\theta} + \frac{1}{2}\frac{\partial A}{\partial \theta}\dot{\theta}^2 = \frac{1}{2}\frac{\partial B}{\partial \theta}\dot{\psi}^2 - \frac{\partial V}{\partial \theta} - \frac{\partial F}{\partial \dot{\theta}},$$

where

$$\frac{\partial B}{\partial \theta} = \frac{\partial \sum mr^2}{\partial \theta} = 2\sum mr\frac{\partial r}{\partial \theta};$$

$$\therefore \quad A\ddot{\theta} + \frac{1}{2}\frac{\partial A}{\partial \theta}\dot{\theta}^2 = \sum mr\dot{\psi}^2\frac{\partial r}{\partial \theta} - \frac{\partial V}{\partial \theta} - \frac{\partial F}{\partial \dot{\theta}}.$$

We may express this equation in terms of the velocity ratios with respect to the rotating frame. Let

$$K_{z\theta} = \frac{\partial z}{\partial \theta} \quad \text{and} \quad K_{r\theta} = \frac{\partial r}{\partial \theta}.$$

Then,

$$\sum m(K_{z\theta}^2 + K_{r\theta}^2)\ddot{\theta} + \sum m\left(K_{z\theta}\frac{\partial K_{z\theta}}{\partial \theta} + K_{r\theta}\frac{\partial K_{r\theta}}{\partial \theta}\right)\dot{\theta}^2$$

$$= \sum mr\dot{\psi}^2K_{r\theta} - \frac{\partial V}{\partial \theta} - \frac{\partial F}{\partial \dot{\theta}}.$$

Thus, in the governor mechanism,

$$z_m = l\cos\theta, \qquad z_q = 2l\cos\theta,$$

$$\frac{\partial z_m}{\partial\theta} = K_{z\theta m} = -\,l\sin\theta, \qquad \frac{\partial z_q}{\partial\theta} = K_{z\theta q} = -\,2l\sin\theta,$$

$$r = \quad l\sin\theta, \qquad \frac{\partial r}{\partial\theta} = K_{r\theta} = l\cos\theta,$$

$$\begin{aligned}&[2m(K_{z\theta m}{}^2 + K_{r\theta}{}^2) + QK_{z\theta q}{}^2]\ddot{\theta}\\ &\quad + \left[2m\left(K_{z\theta m}\frac{\partial K_{z\theta m}}{\partial\theta} + K_{r\theta m}\frac{\partial K_{r\theta m}}{\partial\theta}\right) + QK_{z\theta q}\frac{\partial K_{z\theta q}}{\partial\theta}\right]\dot{\theta}^2\\ &\qquad = 2mrK_{r\theta m}\dot{\psi}^2 - \frac{\partial V}{\partial\theta} - \frac{\partial F}{\partial\theta}\,.\end{aligned}$$

Substituting for the velocity ratios, we obtain

$$\begin{aligned}&[2ml^2 + 4Ql^2\sin^2\theta]\ddot{\theta} + 4Ql^2\sin\theta\cos\theta\ddot{\theta}^2\\ &\qquad = 2ml^2\sin\theta\cos\theta\dot{\psi}^2 - \frac{\partial V}{\partial\theta} - \frac{\partial F}{\partial\ddot{\theta}}\,.\end{aligned}$$

OSCILLATION OF A SYNCHRONOUS MACHINE CONNECTED WITH AN ENGINE MECHANISM.

Let m_r = mass of reciprocating parts,
$m_o k_o{}^2$ = total moment of inertia of flywheel, crank, etc.,
m_c = mass of the connecting rod,
h = distance from crosshead to c. of g. of connecting rod,
k = radius of gyration of rod about crosshead,
r = crank radius, ϕ = obliquity of rod,
P = piston load due to gas pressure,
$c(\omega t - \theta) = \dfrac{\partial P_o}{\partial\theta}(\omega t - \theta)$ = torque reaction of alternator,
ω = synchronous or mean angular velocity.

The kinetic energy of the mechanism is

$$\begin{aligned}T = \tfrac{1}{2}\Bigg[\left(m_r + m_c\left(\frac{l-h}{l}\right)\right)\dot{x}^2 + \left(m_o k_o{}^2 + m_o\frac{h}{l}r^2\right)\dot{\theta}^2&\\ + m_o(k^2 - hl)\dot{\phi}^2\Bigg]&\,.\end{aligned}$$

The coefficient of inertia of the system in terms of the velocity ratios is, therefore,

$$A = \left(m_r + m_c \frac{l-h}{l} \right) K_{x\theta}{}^2 + m_o k_o{}^2 + m_c \frac{h_r{}^2}{l} + m_c(k^2 - hl) K_{\phi\theta}{}^2,$$

where the velocity ratios are

$$K_{x\theta} = r\left(\sin\theta + \frac{r}{2l}\sin 2\theta \right), \qquad K_{\phi\theta} = \frac{r}{l}\cos\theta,$$

$$\frac{dK_{x\theta}}{d\theta} = r\left(\cos\theta + \frac{r}{l}\cos 2\theta \right), \qquad \frac{dK_{\phi\theta}}{d\theta} = -\frac{r}{l}\sin\theta.$$

The equation of motion is

$$A\ddot{\theta} + \left[\left(m_r + m_c \frac{l-h}{l} \right) K_{x\theta} \frac{dK_{x\theta}}{d\theta} + m_c(k^2 - hl) K_{\phi\theta} \frac{dK_{\phi\theta}}{d\theta} \right] \dot{\theta}^2 = PK_{x\theta} + c(\omega t - \theta).$$

If now we let $\theta = \omega t + \epsilon_o + \epsilon$, where $c\xi_o$ is the mean load torque of the synchronous machine, and note

$$\dot{\theta} = \omega + \dot{\xi}, \qquad \dot{\theta}^2 = \omega^2 + 2\omega\dot{\xi}, \qquad \ddot{\theta} = \ddot{\epsilon},$$

then substituting for the velocity ratios and simplifying,

$$\begin{aligned} \left[\frac{m_r{}' r^2}{2}\left(1 + \frac{r^2}{4l^2} \right) + m_o{}' k_1{}^2 + m_c(k^2 - hl)\frac{r^2}{2l^2} \right] \ddot{\xi} + c\xi &= \sum P \frac{dx}{d\theta} - c\xi_o \\ - \Big[m_r{}' r^2 \left(\sin\theta + \frac{r}{2l}\sin 2\theta \right)\left(\cos\theta + \frac{r}{l}\cos 2\theta \right) & - m_c(k^2 - hl)\frac{r^2}{2l^2}\sin 2\theta \Big] (\omega^2 + 2\omega\dot{\xi}) \\ - \Big[m_r{}' r^2 \left(\frac{\cos 2\theta}{2} - \frac{r}{l}\sin\theta\sin 2\theta + \frac{r^2}{8l^2}\cos 4\theta \right) & - m_c(k^2 - hl)\frac{r^2}{2l^2}\cos 2\theta \Big] \ddot{\xi}, \end{aligned}$$

where

$$m_r' = m_r + m_c\frac{l-h}{l}, \qquad m_o'k_1^2 = m_ok_o^2 + m_c\frac{h}{l}r^2,$$

evidently

$$\frac{1}{2\pi}\int \Sigma P\frac{dx}{d\theta} = c\xi_o,$$

so that $\Sigma P\frac{dx}{d\theta} - c\xi_o$ is the reduced torque due to gas pressure over its mean, and can be expanded by Fourier's Series into a harmonic series. The first term on the left is the equivalent mean mass of the mechanism, and the second term is the equivalent "elastic" reaction. The third term on the right when multiplied by ω^2 is the resolved inertia torque due to the moving parts. The terms containing $\omega\dot{\xi}$ and the last term containing $\ddot{\xi}$ on the right side can be omitted in a first approximation.

TORSIONAL OSCILLATIONS IN ENGINE SHAFTS (Fig. 84).

Let $A_1, A_2, \cdots, A_n$ be the reduced inertias with respect to the coördinates $\theta_1, \theta_2, \cdots, \theta_n$ defining the angular displacements of the cranks and fly wheel, where it is to be noted

$$A_1 = f(\theta_1), \qquad A_2 = f(\theta_2), \qquad \cdots \qquad A_n = f(\theta_n).$$

That is, the inertia coefficients are functions of their respective coördinates only.

Let $C_{12}, C_{23}, \cdots C_{n-1,\,n}$ be the elastic constants of the equivalent shafts between the crank centers and aft end crank and fly wheel respectively.

The kinetic energy of the system is

$$T = \tfrac{1}{2}A_1\dot{\theta}_1^2 + \tfrac{1}{2}A_2\dot{\theta}_2^2 \cdots \tfrac{1}{2}A_n\dot{\theta}_n^2.$$

The potential energy of the elastic shafts is

$$\overline{V} = \tfrac{1}{2}C_{12}(\theta_1 - \theta_2 - \alpha_{12})^2 + \tfrac{1}{2}C_{23}(\theta_2 - \theta_3 - \alpha_{23})^2 + \tfrac{1}{2}C_{n-1,\,n} \times (\theta_{n-1} - \theta_n)^2,$$

where α_{12}, α_{23}, etc., are the fixed phase angles between successive cranks.

Let $P_1, P_2, \cdots, P_{n-1}$ be the gas pressures and R the resisting torque at the end of the shaft acting on the coördinate θ_n. The total work of these forces is

$$P\frac{\partial s}{\partial \theta_1}\delta\theta_1 + P\frac{\partial s_2}{\partial \theta_2}\delta\theta_2 + P_{n-1}\frac{\partial s_{n-1}}{\partial \theta_{n-1}}\delta\theta_{n-1} + R\delta\theta_n,$$

where s is the displacement of the piston corresponding to the crank angle θ.

Now since A is a function of θ only,

$$\frac{\partial T}{\partial \dot\theta_1} = A_1\dot\theta_1 = p_1, \qquad \frac{dp_1}{dt} = A_1\ddot\theta + \frac{dA_1}{dt}\dot\theta_1 = A_1\ddot\theta_1 + \frac{dA_1}{d\theta_1}\ddot\theta_1^2,$$

$$\frac{\partial T}{\partial \theta_1} = \frac{1}{2}\frac{dA_1}{d\theta_1}\cdot\dot\theta_1^2 \qquad \text{and} \qquad -\frac{\partial V}{\partial \theta_1} = C_{12}(\theta_2 - \theta_1 + \alpha_{12}),$$

so that from the Lagrangian equations

$$A_1\ddot\theta_1 + \frac{1}{2}\frac{dA_1}{d\theta_1}\cdot\dot\theta_1^2 + C_{12}(\theta_1 - \theta_2 - \alpha_{12}) = P\frac{\partial s_1}{\partial \theta_1},$$

$$A_2\ddot\theta_2 + \frac{1}{2}\frac{dA_2}{d\theta_2}\cdot\dot\theta_2^2 + C_{12}(\theta_2 - \theta_1 + \alpha_{12}) + C_{23}(\theta_2 - \theta_3 - \alpha_{23}) = P_2\frac{\partial s_2}{\partial \theta_2},$$

. . . .

$$I\ddot\theta + C_{n-1,\,n}(\theta_n - \theta_{n-1}) = R.$$

If ω = the mean angular velocity of the shaft, and the additional angular displacements between successive cranks and the aft end crank and fly wheel due to the mean torque load transmitted in these portions be designated by ψ_{12}, ψ_{23}, $\cdots$, $\psi_{n-1,\,n}$, then

$$\theta_1 = \omega t + \epsilon_1,$$
$$\theta_2 = \omega t - \alpha_{12} - \psi_{12} + \epsilon_2,$$
$$\theta_3 = \psi t - \alpha_{12} - \alpha_{23} - \psi_{12} - \psi_{23} + \epsilon_3,$$

and

$$\dot\theta_1 = \omega + \dot\epsilon_1, \qquad \dot\theta_1^2 = \omega^2 + 2\omega\dot\epsilon_1,$$
$$\dot\theta_2 = \omega + \dot\epsilon_2, \qquad \dot\theta_2 = \omega^2 + 2\omega\dot\epsilon_2,$$

. . . .

$$\ddot\theta_1 = \ddot\epsilon_1, \qquad \ddot\theta_2 = \ddot\epsilon_2, \qquad \ddot\theta_3 = \ddot\epsilon_3, \qquad \text{etc.}$$

In a first approximation, neglecting the obliquity of the connecting rod, then for any cylinder q,

$$S_q = r(1 - \cos \theta_q),$$

$$A_q = I_{cq} + m_r r^2 \sin^2 \theta_q = \left(I_{cq} + \frac{m_r r^2}{2} \right) - \frac{m_r r^2}{2} \cos 2\theta_q,$$

$$\frac{1}{2} \frac{\partial A}{\partial \theta_q} = m_r r^2 \sin \theta_q \cos \theta_q,$$

and the reduced piston load is

$$P_q \frac{\partial s_q}{\partial \theta_q} = P_q r \sin \theta_q,$$

where

I_{cq} = moment of inertia of crank and shaft for cylinder q,
m_r = mass of reciprocating parts,
S_q = displacement of piston for cylinder q,
P_q = piston load usually a variable and a function of the angle θ_q.

The piston load torque $P_q r \sin \theta_q$ can be expanded into a harmonic series of the general form

$$R_P = R_{MP} + \sum B \sin n\theta + \sum C \cos n\theta.$$

For any crank the mean torque is

$$R_{MP} = \frac{1}{\pi} \int_0^{\pi} r \sin \theta d\theta,$$

and for q cylinders the mean torque resistance at the generator is

$$R_m = \sum_0^q \frac{1}{\pi} \int_0^{\pi} Pr \sin (\theta - \alpha) d\theta.$$

The mean torque must be in equilibrium with the elastic reactions of the shafts corresponding to their mean or load deflections, that is,

$$C_{12}\psi_{12} = R_{MP_1}, \qquad C_{23}\psi_{23} - C_{12}\psi_{12} = R_{MP_2}, \qquad \text{etc.},$$

and

$$C_{n-1,\,n}\psi_{n-1,\,n} = \sum_{0}^{q} R_{MP} = R_M.$$

Substituting in the equations of motion the values of θ_1, $\theta_2, \cdots, \theta_n$ and their velocities, in terms of the mean values and their variations about the mean we have the equation of motion in the form

$$\left(I_{c1} + \frac{m_1r^2}{2}\right)\ddot{\epsilon}_1 + C_{12}(\epsilon_1 - \epsilon_2)$$

$$= \sum B \sin n\theta_1 + \sum C \cos n\theta_1 - m_rr^2 \sin\theta_1 \cos\theta_1\omega^2$$

$$+ \frac{m_rr^2}{2}(\cos 2\theta_1 \cdot \ddot{\epsilon}_1 - 2\omega \sin 2\theta_1 \cdot \dot{\epsilon}_1)$$

$$\left(I_{c2} + \frac{m_rr^2}{2}\right)\ddot{\epsilon}_2 + C_{12}(\epsilon_2 - \epsilon_1) + C_{23}(\epsilon_2 - \epsilon_3)$$

$$= \sum(B \sin n\theta_2 + C \cos n\theta_2) - m_rr^2 \sin\theta_2 \cos\theta_2 \cdot \omega^2$$

$$+ \frac{m_rr^2}{2}(\cos 2\theta_2 \cdot \ddot{\epsilon}_2 - 2\omega \sin 2\theta_2 \cdot \dot{\epsilon}_2),$$

. . . .

$$I_n\ddot{\epsilon}_n + C_{n-1,\,n}(\epsilon_n - \epsilon_{n-1}) = \Delta R,$$

where approximately

$$\theta_1 = \omega t, \qquad \theta_2 = \omega t - \alpha_1, \qquad \cdots \qquad \theta_n = \omega t - \sum_{0}^{n-1} \alpha_q,$$

and $\alpha_1, \alpha_2, \cdots, \alpha_q$ are the phase angle lags between successive cranks with respect to the forward crank leading.

In a first approximation we may omit the last term in the above expressions. The equations, therefore, reduce to expressions usually assumed in the analysis of torsional oscillations.

We note the equivalent effect of the reciprocating parts is a revolving mass at crank pin radius and of magnitude equal to one-half that of the reciprocating mass. The impressed force has two major components, the torque due to the gas pressures and that due to the inertia loadings of the reciprocating parts. This latter can be readily seen since the inertia load is $m\omega^2r \cos\theta$ and this acts on a moment arm of $r \sin\theta$, with a resulting moment $-m\ {}^2r^2 \cos\theta \sin\theta$.

The mean inertia coefficient of the reciprocating masses reduced to the shaft is

$$M = \frac{1}{2\pi}\int_0^{2\pi} mr^2 \cdot \sin^2 \theta \cdot d\theta = \frac{mr^2}{2}.$$

The resisting torque at the fly wheel end, in the case of an engine driven alternator, is of the form

$$R = R_m + K\epsilon_n,$$

so that

$$\Delta R = R - R_m = K\epsilon_n.$$

That is, the variation of the mean torque due to the electromagnetic reactions is of an " elastic " nature.

REACTIONS OF THE ENGINE FRAME DUE TO TORSIONAL OSCILLATIONS.

Let

T_f = torque reaction of frame on engine mechanism,
A.M. = angular momentum of the moving parts about the shaft axis.

Then for any cylinder, as cylinder No. 2, we have

$$T_{f2} - C_{12}(\theta_2 - \theta_1) - C_{23}(\theta_2 - \theta_3) = \frac{d(\text{A.M.})_2}{dt}$$

or

$$T_{f_2} - R_{m_2} - C_{12}(\epsilon_2 - \epsilon_1) - C_{23}(\epsilon_2 - \epsilon_3) = \frac{d(\text{A.M.})_2}{dt},$$

and, for the total engine,

$$T_f - C_{(n-1,\, n)}(\epsilon_{n-1} - \epsilon_n) - R_m = \frac{d(\text{A.M.})}{dt}.$$

If we neglect the obliquity of the connecting rod and assume its mass concentrated at piston and crank, then the A.M. = $I_{C2}\dot{\theta}_2$, since the kinetic reactions of the reciprocating parts have no moment about the shaft. Therefore the frame reaction is

$$T_{f_2} = R_{m_2} + C_{12}(\epsilon_2 - \epsilon_1) + C_{23}(\epsilon_2 - \epsilon_3) + I_{c_2}\ddot{\epsilon}_2$$

and

$$T_f = R_m + C_{n-1,\, n}(\epsilon_{n-1} - \epsilon_n) + \sum_0^{e} (I_c\ddot{\epsilon}).$$

Substituting for the elastic torque reactions of the shaft and omitting the second harmonic terms of the oscillation terms,

$$T_{f_2} = R_{m_2} + \sum(B \sin n\theta_2 + C \cos n\theta_2) - m_r\omega^2 r^2 \sin\theta \cdot \cos\theta - \frac{m_r r^2}{2}\ddot{\epsilon}_2$$

and

$$T_f = R_m + \sum_0^q \left(\sum(B \sin n\theta_2 + C \cos n\theta_2)\right) - \sum_0^q m_r\omega^2 r^2 \sin\theta \cos\theta - \sum_0^q \frac{m_r}{2} r^2 \ddot{\epsilon}.$$

The first term of these expressions is constant; it, therefore, can not cause any oscillation of the frame. The varying component of the piston torque shown in the second term for a single cylinder causes oscillations and can not be eliminated for any single cylinder. By proper phasing of the cranks it can, however, be reduced or eliminated in the second expression for the engine as a whole. The inertia torque likewise causes oscillations and may be reduced in a multi-cylinder engine and by proper balancing methods. The last term is the component due to torsional oscillations. It depends upon the amplitude of the vibration and may reach large values near a critical speed. It can not be reduced or eliminated by any balancing method or phasing of the cranks.

TIME VECTOR ANALYSIS OF TORSIONAL OSCILLATIONS.

In some problems of torsional oscillations in shafting the effect of friction can not be neglected. For the many cases of steady oscillations under periodic impressed forces the use of time vector diagrams and the equilibrium of the system of time vector forces, i.e., the damping, the inertia, and elastic reactions, can be applied to any assumed mode of oscillation of the system with the advantage of clearly noting the various phase relations of the amplitudes of the loadings. From the displacements and the equilibrium of the time vector forces the equations of the system can be established for the determination of the phase relations and the harmonic amplitudes of the reactions corresponding to given impressed forces.

For the simple system (Fig. 85), subjected to an impressed force $T = A \sin pt$ and a damping proportional to the velocity $\rho\dot{\theta}$ and the elastic reaction of the shaft $c\theta$, we have

$$I\ddot{\theta} + \rho\dot{\theta} + c\theta = A \sin pt.$$

For a solution let $\theta = \theta_0 \sin (pt - \psi)$, so that in terms of the time vectors (Fig. (85*a*))

$$-\overline{Ip^2\theta_0} + \overline{\rho p\theta_0} + \overline{c\theta_0} = \bar{A},$$

where $\bar{A}$ leads $\overline{\theta_0}$ by the angle ψ.

For the equilibrium of the time vectors,

$$A \cos (\psi - \pi/2) - \rho p\theta_0 = 0 \qquad \text{resolving horizontally,}$$

$$A \sin (\psi - \pi/2) + c\theta_0 - Ip^2\theta_0 = 0 \text{ resolving vertically,}$$

and we note

$$\theta_0\sqrt{p^2\rho^2 + (p^2I - c)^2} = A$$

and

$$\psi = \pi/2 + \tan^{-1}\left(\frac{Ip^2 - c}{\rho}\right)$$

For the system (Fig. 86), we have a two-mass system connected by an elastic shaft or coupling with an elastic constant c_{12}. Assume an impressed force on pulley I_1 equal to $T = A \sin pt$ and a damping resistance on pulley I_2 equal to $\rho\dot{\theta}_2$.

The equations of motion of the system are

$$I_1\ddot{\theta}_1 + c_{12}(\theta_1 - \theta_2) = A \sin pt,$$

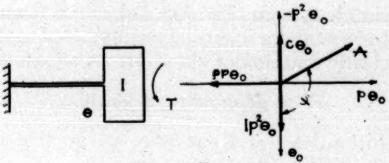
$$I_2\ddot{\theta}_2 + c_{12}(\theta_2 - \theta_1) = -\rho\dot{\theta}_2.$$

For a solution, let

$$\theta_1 = \theta_{01} \sin (pt - \psi) \qquad \text{and} \qquad \theta_2 = \theta_{02} \sin (pt - (\psi + \epsilon)).$$

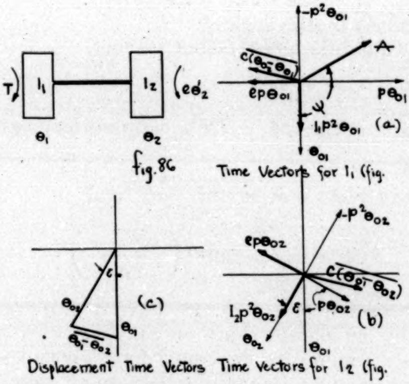
The time vectors are

$\overline{A}$ = the applied force leading the displacement vector $\overline{\theta_{01}}$ by angle ψ or the velocity vector $\overline{p\theta_{01}}$ by $\psi - \pi/2$,



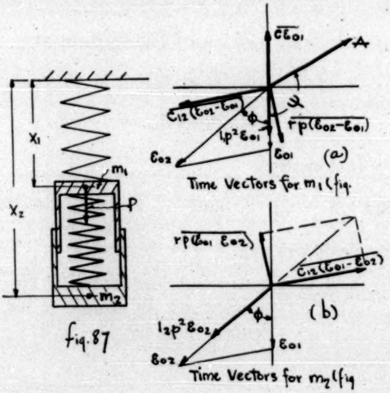
I
T
θ
$-p^2\theta_0$
$c\theta_0$
A
$\rho p\theta_0$
$p\theta_0$
ψ
$Ip^2\theta_0$
θ_0
Time Vectors for I (fig.

fig 85



T
I_1
I_2
$e\theta'_2$
θ_1
θ_2
$-p^2\theta_{01}$
A
$c\overline{(\theta_{02}-\theta_{01})}$
$ep\theta_{01}$
$p\theta_{01}$
ψ
$I_1p^2\theta_{01}$
(a)
θ_{01}
Time Vectors for I_1 (fig.
ε
θ_{02}
(c)
θ_{01}
$\overline{\theta_{01}-\theta_{02}}$
Displacement Time Vectors
$-p^2\theta_{02}$
$ep\theta_{02}$
$c\overline{(\theta_{01}-\theta_{02})}$
$I_2p^2\theta_{02}$
ε
$p\theta_{02}$
(b)
θ_{02}
θ_{01}
Time Vectors for I_2 (fig.

fig.86



X_1
X_2
m_1
P
m_2
$\overline{c\varepsilon_{01}}$
A
$c_{12}\overline{(\varepsilon_{02}-\varepsilon_{01})}$
ψ
φ
$\overline{rp(\varepsilon_{02}-\varepsilon_{01})}$
$I_1p^2\varepsilon_{01}$
ε_{02}
ε_{01}
(a)
Time Vectors for m_1 (fig.
$r\overline{p(\varepsilon_{01}\ \varepsilon_{02})}$
$\overline{c_{12}(\varepsilon_{01}-\varepsilon_{02})}$
φ
(b)
$I_2p^2\varepsilon_{02}$
ε_{01}
ε_{02}
Time Vectors for m_2 (fig

fig.87

$-\overline{I_1\ddot{\theta}_1} = \overline{I_1 p^2 \theta_{01}}$ = the inertia loading of I_1 in phase with the displacement vector $\overline{\theta_{01}}$,

$-\overline{I_2\ddot{\theta}_2} = \overline{I_2 p^2 \theta_{02}}$ = the inertia loading of I_2 in phase with the displacement vector $\overline{\theta_{02}}$,

$-\overline{\rho\dot{\theta}_2} = -\overline{\rho p \theta_{02}}$ = the resistance loading on I_2 in opposite phase with the velocity vector $\overline{p\theta_{02}}$ or lagging by $\pi/2$ the displacement vector $\overline{\theta_{02}}$.

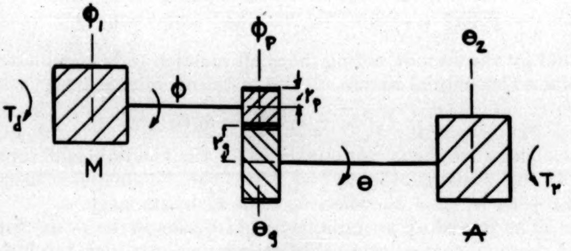

ϕ_1
ϕ_p
θ_2
T_d
ϕ
r_p
r_2
M
θ
T_r
θ_g
A

fig. 88

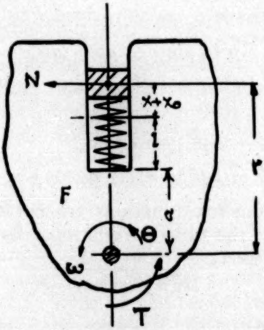

N
$x+x_0$
l
r
F
a
θ
ω
T

fig. 89

The mutual reaction of the shaft is equal to the elastic constant of the shaft times the vector difference of the displacement vectors, that is,

$$\overline{c_{12}(\theta_{02} - \theta_{01})} = \text{the elastic shaft reaction on } I_1,$$
$$\overline{c_{12}(\theta_{01} - \theta_{02})} = \text{the elastic shaft reaction on } I_2.$$

For the equilibrium of the time vectors we have

$$\overline{A} + \overline{I_1 p^2 \theta_{01}} + \overline{c_{12}(\theta_{02} - \theta_{01})} = 0, \qquad \text{for } I_1,$$
$$\overline{I_2 p^2 \theta_{02}} + \overline{c_{12}(\theta_{01} - \theta_{02})} - \overline{\rho p \theta_{02}} = 0, \qquad \text{for } I_2,$$

and for the system, noting the shaft reaction to be eliminated due to its mutual nature,

$$\overline{A} + \overline{I_1 p^2 \theta_{01}} + \overline{I_2 p^2 \theta_{02}} - \overline{\rho p \theta_{02}} = 0.$$

These are the vector equations for the kinetic equilibrium of the system. Finally we have the kinematic relation $\overline{\theta_{01}} + \overline{\theta_{02} - \theta_{01}} = \overline{\theta_{02}}$, where $\overline{\theta_{01}}$ leads $\overline{\theta_{02}}$ by the angle ϵ.

The procedure for an analytical solution is the projection of these vectors on arbitrarily chosen axis. It is to be noted that the projection of the difference of two vectors, as in the elastic reaction, is the difference of the projection of the vectors themselves. We will assume θ_{01} to coincide with the negative of the "y" axis.

To determine θ_{01}, θ_{02}, ψ and ϵ, from the kinetic equilibrium of the system we have

$$A \sin \psi - I_2 p^2 \theta_{02} \sin \epsilon - \rho p \theta_{02} \cos \epsilon = 0,$$
$$- A \cos \psi - I_1 p^2 \theta_{01} + I_2 p^2 \theta_{02} \cos \epsilon - \rho p \theta_{02} \sin \epsilon = 0,$$

and

$$A \sin \psi - c_{12} \theta_{02} \sin \epsilon = 0,$$
$$- A \cos \psi - I_1 p^2 \theta_{01} - c_{12}(\theta_{02} \cos \epsilon - \theta_{01}) = 0,$$

where the trigonometric functions are not independent but are connected by the obvious relations $\cos^2 \psi = 1 - \sin^2 \psi$ and $\cos^2 \epsilon = 1 - \sin^2 \epsilon$.

(*To be continued.*)

COMMITTEE ON SCIENCE AND THE ARTS.

ABSTRACTS OF REPORTS.

GAS CARBURIZING APPARATUS.

HALL OF THE INSTITUTE,
PHILADELPHIA, October 3, 1928.

No. 2893.

The Franklin Institute of the State of Pennsylvania, acting through its Committee on Science and the Arts, investigating the Gas Carburizing Apparatus invented by Mr. Adolph W. Machlet, of Elizabeth, New Jersey, reports as follows:

The apparatus under consideration is used in the case hardening of iron and steel parts such as balls and races of ball bearings, similar parts of roller bearings, many parts of automobiles, sewing machines and agricultural implements; links, pins, bushings of silent chains, similar parts of roller drive chains, automobile skid chains, cap screws, nuts, set screws and many such parts which in use are required to have a hard surface to resist wear.

The object of case-hardening is to produce the hard wearing surface (or "case") on low carbon steel while at the same time retaining the toughness of the "core" of the metal. Small parts like those mentioned are generally made in large quantities from steel of less than .25 per cent. carbon in sheet, bar or wire form. Such steel is relatively soft and can be cut and worked easily and cheaply in machines but parts made of it are not durable when exposed to severe abrasion or pressure. Steel of low carbon analysis will not harden when heated and quenched, but by heating the steel to a temperature of 1500 to 2000° Fahrenheit in contact with a body capable of delivering a carburizing gas, it is carburized, that is, some of the carbon is dissolved in the exposed surfaces of the steel. If the heated parts have thus absorbed carbon so that the surfaces will have about 1 per cent. of carbon to the proper depth, say 1/64 to 1/16 inch, while the core or middle portion retains the original lower percentage of carbon, then if the parts are suddenly quenched, they will have a hard case or skin fit to resist wear, and a tough core to withstand shock and give the necessary strength.

The old process of carburizing, used for many years and known as pack hardening, is to pack the steel parts in iron boxes or pots with some material like wood charcoal, charred bone or leather or mixtures of them with coke dust or cyanides, heat the boxes in a muffle furnace to the proper temperature, maintain that temperature for the necessary time, remove the boxes from the furnace, then empty the contents into the quenching bath. The boxes are allowed to cool so that they can be rehandled, then packed with a new lot of parts and more of the carbonaceous compound and put into the furnace for another heat. During this time the furnace has been cooling down and the consequent loss of heat is one of the objections to the process. Other objections to the pack hardening process are: (1) The boxes must be carefully packed, the steel parts must be completely surrounded with the carbonaceous compound, they must not touch each other nor the sides of the box; (2) The steel parts nearest to the sides of the box receive more carbon than those parts near the middle of the box, and when quenched may have too much hard case or too little tough core; (3) Some of the boxes within the furnace may receive more heat than others and the work after quenching may show a variation in hardness or depth of case.

The Machlet apparatus as made by the American Gas Furnace Company is shown in Plate I. It consists of a barrel shaped furnace mounted on trunnions supplied with necessary fuel pipes and contains a cylindrical retort which receives the work and which rotates on its axis. One projecting end of the retort and the wheels on which it runs are shown in the plate. Plate II taken from the first Machlet patent, No. 822,460 of 1906, shows in cross section, an early type of machine with the pivot at one end instead of at the middle, as it is now made. The iron or steel parts to be case hardened are represented by a dotted line *1*, they are shovelled or dumped into the retort *2* to make it about half full. The furnace shell *5* is lined with refractory brick *8* and has oil pipes *11* which lead the mixture of air and fuel into

PLATE I

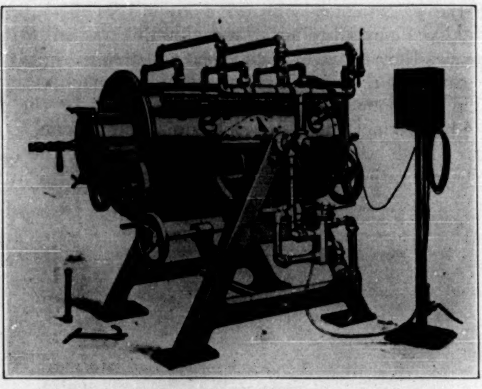
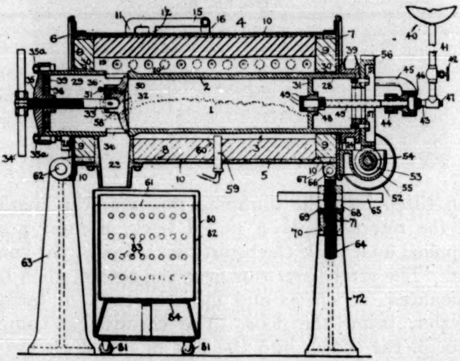


PLATE II


11
12
15
16
4
10
6
7
40
41
42
35a
8
9
39
56
19
30
30
45
46
35
39
29
36
2
31
28
34
50
32
51
49
47
33
1
48
45
57
44
43
58
9
36
8
60
3
9
14
54
34
35a
62
10
23
10
5
19
67
66
53
59
55
61
52
65
80
69
68
82
71
70
83
64
63
72
84
81
81

the flame space *3*. In the retort there is a removable head *32* and a fixed head *31* through which a pipe supplies the carburizing gas. The retort is driven by the worm wheel *56* and a gland at *44* permits the pipe *49* to rotate with the retort while pipe *43* does not rotate. In the carburizing process, illuminating gas may be used, or gas enriched with oil or the retort may contain a quantity of carburizing material like charcoal to act as a cushion to prevent injury to the parts as they roll over each other and also to supply some of the carburizing gas. Some users of the machine employ the solid compound only and supply no gas to the retort because by-product gas is not rich enough in carbon.

Plate III shows two of these machines in use, the far one is in the operating position; on the near one, the furnace has been tilted into the dumping position, the removable head of the retort has been pulled back, a short portable screen applied and, while the retort turns slowly, the contents pour out. The steel parts run over the screen, then over a chute mounted on wheels and into the tank of quenching oil or water, below the floor. The carburizing compound sifts through the screen into the box mounted on the hand truck.

PLATE III

The principle features of the original Machlet patent of 1906 are summed up in claims nine and twenty-nine of the patent:

9. "A case-hardening apparatus comprising a furnace having a flame-chamber, a retort mounted wholly within said flame-chamber, a holder for carburizing fluid connected to said retort, and power-driven means for effecting agitation of the articles within the retort during the heating thereof; means being provided for securing circulation of the carburizing fluid within the retort during the heating thereof."

29. "A case-hardening apparatus comprising a furnace provided with a flame-chamber and a retort, a cover for said retort, means for suppyling iron-carburizing gas to and venting it from said retort, and means for tilting said furnace together with said retort to discharge the articles from said retort."

Since then fourteen other patents have been issued to Mr. Machlet on improvements or modifications of the machine. In itself, it was not new in 1906 to carburize iron or steel in a furnace by means of a gas supplied through pipes, nor to use a rotary furnace with a supply of gas, but the particular form of apparatus covered by the forty claims of the original patent was new at that time, it proved to be successful, and has not been changed much since. So far as the Institute is informed, no other concerns than the American Gas Furnace Company make carburizing apparatus of this type and there has been no litigation over patents. As to the validity and originality of the patents, the Institute is informed that for some years after 1906, these machines were sold on contracts in which the purchasers were asked to acknowledge the validity of the patents and that many concerns—among them the Singer Manufacturing Company and Link Belt Company—made careful investigation of the patents before buying the machines.

The Institute's Committee has corresponded with a number of users of Mr. Machlet's invention, all of whom speak highly of the satisfactory operation of it.

In consideration of his improved method of case hardening and the construction of the apparatus for that purpose whereby the cost of case hardening is reduced, a greater uniformity of hardened surface is secured and the quality of the work kept under control and thereby improved, THE FRANKLIN INSTITUTE awards its EDWARD LONGSTRETH MEDAL to MR. ADOLPH W. MACHLET, of Elizabeth, New Jersey.

The Constitution of Chromium and Molybdenum. F. W. ASTON. (*Nature*, Aug. 9 and Sept. 6, 1930.) The mass-spectra of both of these elements was obtained by using their carbonyls, prepared by Dr. A. v. Grosse of Berlin, to whom Aston generously assigns the credit for the discovery of the molybdenum spectrum. As long ago as 1923 an attempt was made to get the mass-spectrum of chromium but the indistinct results showed only a single line. This had the mass number of 52. With the solid but volatile carbonyl, $Cr(CO_6)$, giving a small but adequate vapor pressure, four isotopes made their appearance, as follows:

Mass number	50	52	53	54
Percentage abundance	4.9	81.6	10.4	3.1

These data lead to the atomic weight of 52.011 ± .006 for chromium. "It will be noticed that the lightest isotope is isobaric with the doubtful Ti^{50} and the heaviest with Fe^{54}."

"Molybdenum has no less than seven isotopes, and the group indicates relative abundance relations far closer than those of any other multiple element so far investigated." Because of incidental difficulties measurements could not be made with the usual accuracy. The isotopes are as follows:

Mass numbers	92	94	95	96	97	98	100
Percentage abundance	14.2	10.0	15.5	17.8	9.6	23.0	9.8

The atomic weight of molybdenum is calculated to be 95.97 ± 0.05. "Two of the isotopes are isobaric with the well-established isotopes of zirconium 92 and 94, and a third with the doubtful one 96."

G. F. S.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

SPECTRUM OF RHENIUM.

The discovery of element 75, rhenium, was announced by the German chemists, Walter Noddack and Ida Tacke, in 1925. The first actual evidence of the existence of the new element was the finding of 3 or 4 new lines in x-ray spectra.

Through the kind donation of one gram of pure potassium perrhenate to the bureau by Dr. A. V. Grosse of the Institute of Technology, Berlin, a study of the emission spectrum of the new element was made possible. Measurements have now been made by W. F. Meggers at the Bureau of Standards of the arc spectrum of rhenium in the region from 2300 A. in the ultra-violet to 8800 A. in the infra-red. Approximately 2,000 lines have been discovered, all of which are new to the science of spectroscopy, since they are not identifiable with lines emitted by any other known atoms.

A partial list of principal lines characteristic of neutral rhenium atoms is as follows:

Wave-length Angstrom Units.	Relative Intensity.	Wave-length Angstrom Units.	Relative Intensity.
2887.66	60	4394.37	80
2992.35	50	4513.31	300
2999.59	80	4516.62	50
3067.38	50	4522.71	100
3399.31	60	4791.42	80
3424.61	120	4889.15	2000
3451.88	200	4923.93	80
3460.46	600	5270.98	400
3464.72	400	5275.57	1000
3725.76	50	5834.31	300
4136.45	100	6307.70	75
4144.36	60	6321.88	100
4222.46	200	6350.73	50
4257.61	50	6605.17	60
4358.69	50	6813.37	100
		6829.91	120
		6971.48	60
		7024.10	50
		7640.92	80
		7912.90	50

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* Communicated by the Director.

Most, if not all, of the above lines are complex; the wavelength is a mean value of the unresolved components.

The strongest line in the *Re* spectrum is 4889.15 A.; it is undoubtedly the most sensitive line for the spectro-chemical identification of rhenium. This blue line and the green ones at 5270.98 and 5275.57 A. are the most brilliant lines in the visible spectrum. The ultra-violet ones at 3451.88, 3460.46, and 3464.72 are also very intense and persistent.

An analysis of the spectrum is in progress; it appears that the normal state of the *Re* atom is represented by a sextet *S* term which is to be expected from seven valence electrons.

Rhenium, the existence of which was predicted sixty years ago by Mendeléev, is an extremely rare element, and this probably explains why it was not discovered sooner. It is estimated that it constitutes about one part in a million million of the earth's crust.

SEPARATION AND GRAVIMETRIC DETERMINATION OF OSMIUM.

A new method for the gravimetric determination of osmium has been developed at the bureau and will be described in the March number of the *Bureau of Standards Journal of Research.* This method successfully overcomes the difficulties which have heretofore been experienced and offers a simple and accurate means for the determination of this metal.

The method may be briefly described as follows: Osmium tetroxide, separated from other metals by distillation with nitric acid, is absorbed in 6 normal hydrochloric acid saturated with sulphur dioxide and contained in two receiving flasks attached to a distilling flask by carefully ground joints. After the distillation is complete the receiving solution is evaporated on the steam bath. The residue, which will not go quite to dryness because of the sulphuric acid formed by oxidation with the nitric acid which distils with the osmium tetroxide, is digested for 15 minutes with a small amount of strong hydrochloric acid. This digestion and evaporation are repeated three more times to insure complete decomposition of sulphite compounds of osmium. The concentrated osmium solution is diluted with water to about 150 ml. and heated to boiling. A dilute solution of sodium bicarbonate is added to the boiling solution until the acidity reaches pH 4, indicated by a faint bluish color of brom phenol blue indicator. At this acidity the osmium is completely precipitated as hydrated osmium dioxide, which coagulates well and settles quickly for 5 minutes. The precipitate is filtered on a Gooch, or preferably on a Monroe, crucible and thoroughly washed with a hot one per cent. solution of ammonium chloride. After washing is completed the precipitate is moistened with a strong solution of ammonium chloride. This treatment entirely overcomes the tendency of the hydrated dioxide to deflagrate on subsequent ignition. The hydrated dioxide is heated in an atmosphere of hydrogen, cautiously at first until the ammonium chloride has been expelled, then to bright redness for a few minutes. The reduced metal is cooled nearly to room temperature in hydrogen and finally in carbon dioxide. The osmium thus recovered is weighed as metal.

FUSIBLE ALLOYS OF BISMUTH.

Fusible alloys of bismuth, lead, and tin, and of bismuth, lead, tin, and cadmium have been known for a long time. A number of the alloys are completely molten at temperatures well below that of boiling water and many of them possess mechanical and other properties which have been utilized in various ways.

The history, uses and composition of these fusible alloys are discussed in Bureau of Standards Circular No. 388 which was issued last month. Tables of fusible alloys arranged in order of their melting points are presented. Cooling curves indicate that 70° C. is the lowest solidification point obtainable in the alloys of bismuth, lead, tin, and cadmium. The question of volume changes in the alloys during and after solidification is briefly discussed.

Copies of this circular may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents each.

SHORT-TIME TEST FOR METALS UNDER STRESS AT ELEVATED TEMPERATURES.

With the development of present-day power houses, oil refineries, chemical plants, and allied industries there has arisen an increasing demand for better materials of construction together with definite information on the behavior of commercial metals which are required to operate at high pressures and temperatures. This applies to a variety of properties, but in particular to the behavior of metals when subjected to fixed loads for long periods of time.

The measurement of the "flow" or "creep" in a tensile test specimen loaded at an elevated temperature for several hundred hours is regarded as the best test by which the suitability of metals may be judged for severe service conditions. In direct contrast to this test, which is necessarily slow, is the "short-time" test in which a tensile specimen at an elevated temperature is broken in a relatively short period by the application of a steadily increasing load. This latter test affords preliminary information with a great saving of time in the study and development of alloys for service at high temperatures.

In a report in the February number of the *Bureau of Standards Journal of Research*, results are given of "short-time" tension tests at different temperatures for twelve commercial alloys of iron with varying proportions of nickel, chromium, tungsten, vanadium, molybdenum, or aluminum in the wrought condition, either forged or rolled, after which operation many had been heat-treated. A study was also made of the effect of deformation on the structural stability and subsequent hardness at ordinary temperatures.

In general, the results showed that the "long-time" or flow test cannot be satisfactorily replaced by the simpler short-time test although the latter is very valuable for a preliminary study.

USE OF WHITTEMORE STRAIN GAGE.

An interesting example of the use of the Whittemore strain gage in the measurement of stresses in indeterminate structures is given in the February number of the *Bureau of*

Standards Journal of Research. In the case in question, slight outward motion of the brick piers supporting the dome of the natural history building of the National Museum in Washington caused cracks in the masonry joints in the pedentives and in the stone arches under them. It was necessary to reinforce the structure by surrounding the pedentives with a steel framework. Screw jacks were placed between this framework and the masonry to push against the pedentives and prevent further movement. The determination of the load carried by each jack was a difficult matter. The problem was solved by using the Whittemore strain gage at numerous positions on the steel framework, to measure the magnitude of the stresses in the steel. The desired uniformity of pressure from the jacks could thus be secured.

This strain gage can be used to measure differences in distance between gage marks of 0.0001 inch. In a gage length of 10 inches this difference corresponds to a change in stress of about 300 lbs./in.^{2}, which is negligible in most engineering structures where the allowable safe working stress is often 16,000 lbs./in.^{2}

This report is entitled "Strain Measurement in the Reinforcement for the Dome of the Natural History Building" and will be available later in separate form as Research Paper No. 268.

THE MECHANISM OF THE ATOMIZATION OF LIQUIDS.

Automobile carburetors, fuel oil burners, throat sprays, perfume atomizers, and many other commercial and industrial appliances employ a high-speed air stream to convert a mass of liquid into a cloud of fine droplets. The process is called atomization, and occurs also when liquid under pressure is forced through a nozzle into relatively still air, as in the high-speed Diesel engine.

A study has been made at the bureau to determine just how atomization takes place, with particular reference to the use of liquid fuels in internal combustion engines. Spark photographs of water atomization in a glass carburetor give the impression that the droplets are picked directly from the liquid mass but the true explanation appears to be that tiny threads of liquid are torn away and these collapse to form the drops. Recent German measurements of drop sizes show that the liquid filaments producing drops must be so fine that they break up within a ten thousandth of a second.

The complete report on this work will be published in the March number of the *Bureau of Standards Journal of Research.*

APPARATUS FOR MEASURING THERMAL TRANSMISSION OF TEXTILES.

The apparatus for measuring thermal transmission of textiles which is briefly described below was devised by the textile section of the bureau to fill the need for a less elaborate apparatus than that described in Technologic Papers Nos. 266 and 269. The advantages of the new apparatus over the old are that it is simpler to construct and to operate; requires a smaller sample for test (a piece 8 inches in diameter); gives results more rapidly (approximately ½ hour required for test); and is compact and portable. The values obtained with it for relative thermal transmission are in good agreement with those obtained with previous equipment and by different methods in other laboratories.

The new apparatus is essentially a heating element fitted into the opening of a vacuum (thermos) jar. This element consists of a metal disk which can be heated by means of a coil placed below it in the jar. A cavity in the disk is connected with a capillary and is filled with mercury which expands and contracts as the plate is heated or allowed to cool. The fluctuating mercury column in the capillary makes or breaks an electrical contact in a circuit which, operating through a relay, throws the current off or on in the heating coil and thus maintains the disk at a constant temperature. The specimen to be tested is clamped over the disk. When a state of thermal equilibrium is established within the thermos jar the test is begun. The temperature of the surface of the disk is measured with a thermocouple. It is only necessary to time the intervals during which the current in the heating coil is off and on (with stop watches) and to measure the current passing through the heating coil (with an ammeter). The quantity of heat supplied during the test is thus known and is equal to the quantity of heat transmitted through the specimen. The result is conveniently expressed in calories per second per degree Centigrade.

The apparatus is used in a room in which the temperature and relative humidity are kept constant.

THE MAKING OF MIRRORS BY DEPOSITION OF METAL ON GLASS.

The bureau has just issued a new Circular No. 389, which supersedes letter circular No. 32, "Methods of Silvering Glass." It deals principally with the methods for producing mirrors by the chemical deposition of silver on glass. The Brashear, Rochelle salt, and formaldehyde formulas are given, together with a detailed discussion of the precautions which should be taken to avoid danger, and the technique which has been found to yield the most satisfactory results at the bureau. Methods are also given for the chemical deposition of copper, platinum, or lead sulphide and for the production of reflecting films on glass by cathode sputtering, and by the condensation of vaporized metals.

The information will be of great interest to amateur and professional makers of telescopes and other optical instruments, as well as to those engaged in the work of silvering ordinary mirrors.

Copies may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 5 cents each.

MOISTURE EXPANSION OF CERAMIC GLAZES.

In studying the resistance of glazes to "moisture crazing." the bureau has found that, under the action of water, certain glazes expand in a manner similar to that of the ceramic bodies to which they are applied. Although a control of this type of expansion is very important in fitting glazes to bodies, it has not been previously considered. Its importance should be evident at once when it is understood that a large "moisture expansion" in a glaze, or other finish, is in many cases an indication that the glaze will not be so liable to craze when the ceramic ware or material on which it is used is exposed to moisture. This follows because the glaze and the body on which it goes and which is ordinarily very susceptible to this kind of expansion will then increase in size simultaneously and more nearly at the same rate. Such conditions lessen the tendency of the body expansion to cause tensile stresses in the glaze.

In the bureau's investigation specimens of various finishes were subjected to steam at a pressure 150 lbs./in.^{2} for one hour, since it was known that this treatment produces effects similar to those caused by long exposure to weather. This artificial weathering treatment caused lustrous glazes to expand on the average 0.004 per cent., mat glazes 0.011 per cent., vitreous slip finishes 0.005 per cent., and porous slip finishes 0.033 per cent. The moisture expansion of one of the mat glazes was 30 per cent. of the average obtained for a ceramic body having an absorption of approximately 12 per cent. This proclivity of ceramic finishes to expand by the absorption of moisture can be controlled in their manufacture.

The March number of the *Bureau of Standards Journal of Research* will contain a more complete report on this work.

INDEX OF REFRACTION OF SOME SODA-LIME GLASSES AS A FUNCTION OF THEIR COMPOSITION.

Reference to this subject was made in Technical News Bulletin No. 155 (March, 1930), and three equations were given from which the index of refraction of 35 experimental glasses could be computed from their composition with a fair degree of accuracy. A brief statement was also given regarding the melting and testing of the glasses.

Since that report, seven additional glasses were made to check a few questionable points and to increase the range of compositions. Furthermore, additional mathematical studies were made of the data and more satisfactory relations have been obtained. In one of these it was assumed that the effect of soda on index was a linear function, and any departure from a straight line was ascribed to the silica. On this basis two expressions for the index of the soda-silica glasses in terms of their composition were obtained. Substituting values obtained from these expressions in the data for the soda-lime glasses, yields a first power expression for the effect of lime. The expressions for the "partial indices" according to this solution are as follows:

$$
\begin{aligned}
(n - 1) \text{ due to } SiO_2 &= 0.005941A - 0.00001354A^2,\\
(n - 1) \text{ due to } Na_2O &= 0.005054B,\\
(n - 1) \text{ due to } CaO &= 0.00707C,
\end{aligned}
$$

in which A, B, and C are the percentages of SiO_2, Na_2O and CaO respectively in a glass. The index of refraction of the glass, $N - 1$, is the sum of the "partial indices" obtained from the equations given above.

If the indices of the soda-silica glasses are plotted on a sufficiently large scale, it becomes evident that three straight lines can be drawn through the plotted points with greater accuracy than any single curve. From this plot three different expressions for soda and silica were obtained and these apply only in a limited range of compositions. Applying these data to the soda-lime glasses, an expression for lime was obtained.

The index of refraction of all the glasses in the series studied can be expressed by the following equation:

$$N - 1 = aA + bB + cC$$

in which A, B, and C are the percentages of silica, soda, and lime respectively; a, b, and c are the corresponding constants which are different for different ranges of silica, as follows:

Silica Range.	*a.*	*b.*	*c.*
Per cent.			
50 –59.5	0.004836	0.005491	0.007521
59.5 –73.75	.004785	.005568	.007598
73.75–100	.004584	.006127	.007977

It is interesting to note that the two intersections of these three straight lines occur at points corresponding approximately to certain definite soda-silica compounds, viz., $3SiO_2 \cdot 2Na_2O$ and $3SiO_2 \cdot Na_2O$. This suggests that the soda-silica glasses in the three groups might be regarded as simple mixtures of the end members, but more work must be done in order to definitely establish this point. This additional work is now under way.

CAST STONE.

The study of the properties of cast stone previously reported in the Technical News Bulletin (No. 128, December, 1927; No. 138, October, 1928; and No. 143, March, 1929) has been continued and several interesting samples have been added. One of these samples had a compressive strength of 21,700 lbs./in.^{2}, and an absorption of 2.3 per cent. in 24 hours and of 2.4 per cent. in 48 hours—very unusual characteristics for concrete. The manufacturer of this sample states that the samples were made by the vibration process, followed by steam curing.

The freezing tests of many cast stones have been carried on for many more cycles. The best sample has withstood the repetition of 1,400 cycles without signs of disintegration, and a number of samples have gone for over 500 cycles before the first minute signs of disintegration were observed.

The data have been studied to determine if possible some characteristic or group of characteristics that would give information on the resistance of the stone to destruction by freezing and thawing. All characteristics, such as absorption, porosity, compressive strength, and cross bending strengths show a slight correlation with the resistance to freezing. The greater the compressive strength, or the modulus of rupture, and the less the absorption, the greater the resistance to freezing. The correlation is so slight, however, that to assign a minimum or maximum value to any of these characteristics that would eliminate all the weaker samples would also eliminate at least nine tenths of all the samples. No combination of all the factors has been discovered that will give a better correlation with the freezing tests.

A number of the samples were examined microscopically to compare the component aggregates and the resistance of the samples. One sample that showed very poor resistance contained aggregate that was almost all calcite. However, the most resistant sample was also almost all calcite. Apparently the composition of aggregate gives no information on the relative resistance of the sample to freezing.

A suggested specification containing requirements that will eliminate all the poorer samples is as follows:

The compressive strength must be 4,000 lbs./in.^{2} or greater; the 48 hours absorption in water at 18 to 24° C. is required to be less than 10 per cent. by weight, and that upon boiling of the specimen 5 hours subsequent to the 48 hour absorption must be less than 12 per cent. If the 48 hour absorption is greater than six per cent. then the ratio of the 48 hour absorption to the boiling absorption is required to be greater than 0.6 and less than 0.9. However, the introduction of an upper and a lower limit was the only means found to eliminate cast stone of poor resistance without eliminating a much larger proportion of samples with good resistance.

RESISTANCE OF METALS, SUITABLE FOR DIES, TO THE ABRASIVE ACTION OF PLASTIC CLAY.

A brief description of the purpose and mode of attack of this investigation appeared in Technical News Bulletin No. 159 (July, 1930).

When the extrusion pressure increases the abrasion loss also increases. Early in the investigation the data seemed to indicate that the relation between extrusion pressure and abrasion loss was directly proportional. This evidence, however, was questionable inasmuch as the data at hand were limited.

Recently the data obtained from nearly 200 tests have been analyzed and the equation determined which represents the relation between extrusion pressure and abrasion loss. The logarithmic equation deduced is $n \log y = \log x - \log c$, which expressed numerically becomes $y^n = x/c$ in which y = the abrasion loss, and x = the extrusion pressure. n and c are constants for materials having the same "wear values" but differ for materials of different "wear values." For metals and alloys of increasing resistance to abrasion the value of n diminishes and c increases and the opposite is true for those of less resistance to abrasion.

If $y^n = x/c$ represents the equation for metal A and $m = x/d$ for metal B, where the extrusion pressure "x" is the same, then $cy^n = d^m$ from which the comparative abrasion losses of the two metals can be calculated.

STRENGTH AND DURABILITY OF BOND BETWEEN MORTAR AND BRICK.

In a paper which will be published in the March number of the *Bureau of Standards Journal of Research*, bond is considered as the adherence of mortar to brick. Units were stored out of doors, in the laboratory, and in a humid room for two months prior to submission to 50 cycles of alternate freezing and thawing of moisture saturated units. Durability of bond was measured by observing and recording the failures of bond among test units composed of two brick bonded together with mortar. Strength of bond was determined by pulling the bricks apart after the units had been in storage for six months, the same conditions of storage obtaining for both strength and durability tests.

At least 216 units were made with each of four different manufacturers' brick and one mortar. Each manufacturer's shipment of brick was divided into six groups, each of which represented a definite absorption range as determined by immersion for 48 hours in water. The rates of absorption were also determined. There were 432 units made with a fifth manufacturer's brick in connection with the study of bond durability as related to the type of mortar used and also to the degree of loading which the bonded units endured during the durability tests. Brick were set dry, 50 per cent. and 80 per cent. saturated, and with and without metal lugs embedded in the mortar joint, it being considered that this latter condition would indicate the effect of shrinkage of the mortar on bond durability.

Durability of bond was increased by maintaining a load on the units throughout the tests comparable in magnitude to that existing in the base of a wall. It was indicated that the bond in vertical and non-load-bearing joints in masonry generally would fail soonest under severe weathering conditions. There was a marked decrease in durability of bond when metal lugs were embedded in the joint, the height of the lugs being about equal to the thickness of the joint. Wetting brick is very necessary if the brick absorb water rapidly. This fact was very apparent when brick were used which had a rate of absorption such that on standing them on end in water, the top surfaces became wet within less than an hour. It was not necessary to wet brick through which water travelled from edge to edge in more than four hours when stood on edge in water. Of the two mortars, 1 volume Portland cement : 3 volumes sand, and 1 volume hydrated lime : 1 volume Portland cement : 6 volumes sand, the durability of bond was increased slightly through the use of the former. However, it was indicated that the ratio, strength of bond to tensile strength, was greater in the 1 : 1 : 6 mortar. Durability of bond was apparently not dependent to any appreciable extent upon any property of the brick. However, all other things being equal, the strength of bond was improved slightly by the use of relatively porous brick. The data indicate that under the conditions of testing, bond durability and strength are not necessarily related.

On Ozone and Atomic Oxygen in the Upper Atmosphere. S. CHAPMAN. (*Phil. Mag.*, Sept., 1930.) There are few methods by which the composition of the upper regions of the atmosphere can be determined. One of these is by a study of the spectrum of the aurora. Vegard and, later, McLennan with his coadjutors have pursued this course and, thanks to the work of the Canadian investigator, it is now known that the origin of the green line of the aurora is in oxygen. Indeed it is atomic oxygen that is responsible for the line. We thus have "direct evidence of the permanent existence of atomic oxygen (in the neutral state) in some stratum of the upper atmosphere."

In the present paper the author considers the conditions under which an oxygen molecule is dissociated into atoms, under which ozone is formed and decomposed and under which certain additional combinations and reversions of atomic and molecular oxygen and ozone occur. Some of these reactions take place only when a third particle is present along with the two directly concerned, and the probability of such a third particle's appearing is dependent on the density of the atmosphere. In spite of the speculative nature of the assumptions on which the quantitative discussion is based conclusions (1) and (2) below seem very probable. "The existence of ozone implies a mechanism which will form atomic oxygen by dissociating oxygen molecules; this mechanism is almost certainly, at least in part, ultra-violet radiation, which will be absorbed gradually as it passes through the highest atmospheric strata, there dissociating oxygen. At sufficiently great heights recombination will be slow, so that little ozone will be formed, and atomic oxygen will accumulate; and it will rise by diffusion until (in the absence of hydrogen and helium), together with atomic nitrogen, it becomes the chief atmospheric constituent. These, in brief, are the reasons which render it likely that (1) the ozone concentration diminishes rapidly with height above the level of maximum concentration, and especially above the level at which convective mixing is important, and (2) the atomic oxygen concentration increases upwards until it exceeds that of molecular oxygen."

G. F. S.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING FEBRUARY 18, 1931.

The regular monthly meeting of the Institute was called to order at eight-fifteen by Mr. Nathan Hayward, the President. He at once called upon the Secretary for a statement of the business of the evening.

The Secretary reported that the minutes of the January meeting of the Institute had been published in full in the Journal of the Institute for February, which number is now in the hands of the membership, and moved that the minutes as printed therein be approved. The motion was seconded and unanimously adopted.

The Secretary stated that since the last report concerning membership, the following additions had been made: One Non-Resident Life Member; four Resident Members; seven Non-Resident Members; ten deaths.

The Secretary reported that the Board of Managers, upon recommendation of its Committee on Science and the Arts, had awarded a Franklin Medal to Sir James Hopwood Jeans of London, England, and one to Dr. Willis R. Whitney, Director of the Research Department of the General Electric Company, Schenectady, N. Y., and that it was expected to present these medals in person to the two recipients of them at the Medal Day meeting of the Institute, to be held on the twentieth of next May. He stated that it was the practice of the Institute to elect to Honorary Membership those to whom Franklin Medals had been awarded and therefore requested that some member of the Institute present move the election of the two gentlemen named, to Honorary Membership. This motion was immediately offered and seconded and was unanimously adopted.

The Secretary announced at this time the President had to appoint two Institute committees, namely: The Committee on Library and the Committee on Meetings, and that he would read, at the request of the President, the personnel of the two committees:

Committee on Library

C. W. Bates
H. J. M. Creighton
F. L. Garrison
Clarence A. Hall
Joseph S. Hepburn
George A. Hoadley
Lionel F. Levy
Malcolm Lloyd, Jr.
M. M. Price
George F. Stradling

Committee on Meetings

James Barnes
George S. Crampton
T. G. Delbridge
W. H. Fulweiler
Arthur W. Goodspeed
Howard McClenahan
Charles Penrose
George D. Rosengarten
James G. Vail
W. C. Wagner

He then announced that at the meeting of the Board of Managers held today, Mr. Elisha Lee, first Vice-President of the Pennsylvania Railroad System, had been elected to membership in the Board of Managers and that Mr. Lee had signified his acceptance of the election. He expressed much satisfaction over this action by the Board and by Mr. Lee.

The Secretary further announced that at the organization meeting of the Board of Managers, that Board had elected the following gentlemen to constitute the class of members in the Committee on Science and the Arts whose term expires in January, 1934:

James Barnes
Charles E. Bonine
Harold Calvert
G. H. Clamer
H. J. M. Creighton
Samuel B. Eckert
Hiram B. Ely
Frank B. Evans, Jr.
Benjamin Franklin
W. H. Fulweiler
Charles D. Galloway
Clarence A. Hall
Joseph S. Hepburn
John B. Klumpp
William N. Jennings
Lionel F. Levy
H. H. Quimby
L. F. Rondinella
Coleman Sellers, 3d
James Stokley

He finally announced that at the recent meeting of the Committee on Science and the Arts, Mr. Lionel F. Levy had been elected Chairman for the current year.

There being no further business the President introduced Dr. K. C. D. Hickman as the speaker of the evening and stated that he would talk on the subject, "High Vacuum Technique in Chemical Work."

Dr. Hickman spoke delightfully on the developments of methods of producing high vacua and of the important and valuable results obtained at the Eastman Kodak Laboratories by the application of high vacua in chemical researches, particularly in connection with the organic compounds. The lecture was profusely illustrated by lantern slides and experimental apparatus.

After an expression of appreciation to Dr. Hickman for the trouble that he had taken and for the quality of his talk, the meeting adjourned with a rising vote of thanks, at nine-forty-five p.m.

HOWARD MCCLENAHAN,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of Stated Meeting held Wednesday, February 11, 1931.*)

HALL OF THE COMMITTEE,
PHILADELPHIA, FEBRUARY 11, 1931.

MR. HENRY B. ALLEN, *in the Chair.*

The Chairman announced the reelection by the Board of Managers of eighteen members of the Committee to serve for three years and the election of one new member to serve for the same period.

The Special Committee on Nomination of a Chairman for the ensuing year reported as its choice Mr. Lionel F. Levy. Mr. Levy was unanimously elected and took the Chair.

The following reports were presented for first reading:

No. 2919: Telephone Transmitter.
No. 2935: Literature.

GEO. A. HOADLEY,
Secretary to Committee.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(*Stated Meeting Board of Managers, February 18, 1931.*)

RESIDENT.

MR. ABRAHAM D. CAESAR, Attorney at Law—Specializing in Patents, Suite 707, 1321 Arch Street, Philadelphia, Pennsylvania.

MR. J. J. CUMMINGS, Radio and Electrical Engineer, 434 North Seventh Street, Camden, New Jersey.

MR. WILLIAM MELAS, Instrument Development and Design, Cochrane Corporation, Seventeenth Below Allegheny Avenue, For mailing: 114 South Forty-ninth Street, Philadelphia, Pennsylvania.

MR. JESSE ORMONDROYD, Mechanical Engineer, W. E. & M. Company, South Philadelphia Works, Lester Branch Post Office, Lester, Pennsylvania. For mailing: 404 Cornell Avenue, Swarthmore, Pennsylvania.

MR. ERNEST R. RECHEL, Chemist, Frankford Arsenal, Philadelphia, Pennsylvania. For mailing: 4812 Penn Street, Frankford, Philadelphia, Pennsylvania.

NON-RESIDENT.

DR. CHARLES EDWARD BERGER, Instructor of Physics, Department of Physics, Lehigh University, Bethlehem, Pennsylvania.

MR. G. B. KERSEY, Electrical Engineer, 72 West Adams Street, Chicago, Illinois. For mailing: Hinsdale, Illinois.

MR. BERNARD RHODES, Factory Specialist in Electrical Engineering, Physics, The Gramophone Company Ltd., Hayes, Middlesex, England. For mailing: Posta Kutusu 579, Istanbul, Turkey.

DR. FRANK CLIFFORD WHITMORE, Dean, School of Chemistry and Physics, The Pennsylvania State College, State College, Pennsylvania. For mailing: 300 South Pugh Street, State College, Pennsylvania.

CHANGES OF ADDRESS.

MR. C. E. BENNETT, Okonite Callender Cable Company, Paterson, New Jersey.

MR. WILLIAM L. BROWN, 3D, Room 203, 1600 Arch Street, Philadelphia, Pennsylvania.

BRIGADIER GENERAL JOHN J. CARTY, Winter Park, Florida.

MR. JOHN GRAHAM FOLEY, A. B. See Elevator Company, Inc., 52 Vesey Street, New York City, New York.

MR. EARL L. KOCH, 2307 Farwell Avenue, Chicago, Illinois.
MR. HORACE E. MOORE, 206 Edgemont Street, Media, Pennsylvania.
MR. FRANK C. ROBERTS, JR., Cherry Lane, Wynnewood, Pennsylvania.
MR. JOSEPH ROSIN, 410 West Seventh Street, Plainfield, New Jersey.
MR. FREDERICK W. SALMON, 346 Pine Street, Providence, Rhode Island.
MR. EDWARD B. TEMPLE, Chief Engineer, Pennsylvania Railroad, 607 Broad Street Station, Philadelphia, Pennsylvania.
MR. ASA W. WHITNEY, 1704 Windsor Avenue, Bristol, Tennessee.

NECROLOGY.

Mr. Edward F. Henson, Philadelphia, Pennsylvania.
Mr. Benjamin L. Murray, Rahway, New Jersey.
Mr. George S. Webster, Philadelphia, Pennsylvania.
Mr. T. Broom Belfield, Philadelphia, Pennsylvania.

LIBRARY NOTES.

RECENT ADDITIONS.

AGRICOLA, GEORGIUS. De Re Metallica. Libri xii. Quibus Officia, Instrumenta, Machinae, ac Omnia Denique ad Metallicam Spectantia, non modo Luculentissime Describuntur, sed et per Effigies, suis Locis Insertas, Adiunctis Latinis, Germanisque Appellationibus Ita ob Oculos Ponuntur, ut Clarius Tradi non Possint. 1561.
AUER, ALOIS. Der polygraphische Apparat oder die verschiedenen Kunstfächer der K. K. Hof- und Staatsdruckerei zu Wien. I und II Vortrag. 1853.
AUERBACH, FELIX. The Zeiss Works and the Carl Zeiss Foundation in Jena. No date.
Bulletin Almanac and Year Book. 1931.
BUSHNELL, CHARLES H. Diesel Engine Operation, Maintenance and Repair. 1930.
CALDWELL, FRANK C. Modern Lighting. 1930.
CHENEY, SHELDON. The New World Architecture. 1930.
CHENOWETH, W. W. Food Preservation. 1930.
CLERC, L. P. Photography: Theory and Practice. Being an English edition of "La Technique Photographique." 1930.
CRUESS, W. V. Commercial Fruit and Vegetable Products. First edition. 1924.
DALAKER, HANS H., AND HENRY E. HARTIG. The Calculus. 1930.
DEMING, HORACE G. General Chemistry: an Elementary Survey Emphasizing Industrial Applications of Fundamental Principles. Third edition, rewritten and revised. 1930.
Deutsche Lichtbild. Jahresschau. 1930.
DEWS, H. C. The Metallurgy of Bronze. 1930.
EDDINGTON, A. S. Internal Constitution of the Stars. 1926.

ELLIS, CARLETON. Hydrogenation of Organic Substances, Including Fats and Fuels. Third edition, re-written and enlarged. 1930.
ETCHEVERRY, BERNARD A. Land Drainage and Flood Protection. 1931.
EZEKIEL, MORDECAI. Methods of Correlation Analysis. 1930.
FANSHAWE, JOHN R. A Microscopical Study of Coal. 1930.
FINDLAY, ALEXANDER. The Spirit of Chemistry. 1930.
FISK, WALTER W. The Book of Ice Cream. New Edition. 1927.
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HALDANE, J. B. S. Enzymes. 1930.
HAZEN, ALLEN. Flood Flows: a Study of Frequencies and Magnitudes. 1930.
HÉRISSE, EMILE. Pastry-Making and Confectionery. New edition by C. Herman Senn. No date.
International Critical Tables of Numerical Data, Physics, Chemistry, and Technology. Volume 7 and Index. Two volumes. 1930.
JAFFE, BERNARD. Crucibles: the Lives and Achievements of the Great Chemists. 1930.
JOHANNESSON, SIGVALD. Highway Economics. 1931.
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Klimschs Jahrbuch der graphischen Künste. Band 24. 1931.
KOSSEL, ALBRECHT. The Protamines and Histones. 1928.
LEA, FREDERICK CHARLES. Hydraulics for Engineers and Engineering Students. Fifth edition. 1930.
MCCOLLUM, E. V. A Text-book of Organic Chemistry for Students of Medicine and Biology. Second edition, revised. 1923.
MCMURRICH, J. PLAYFAIR. Leonardo da Vinci, the Anatomist. 1930.
NEUBURGER, ALBERT. The Technical Arts and Sciences of the Ancients. Translated by Henry L. Brose. 1930.
Photograms of the Year 1930.
PORTA, JOHN BAPTISTA. Natural Magick. 1658.
PORTER, C. W. The Carbon Compounds: A Text-book of Organic Chemistry. Revised edition. 1926.
PRYDE, JOHN. Recent Advances in Biochemistry. Third edition. 1931.
SALMON, E. H. Materials and Structures. Volume I Elasticity and Strength of Materials. 1931.
SHAND, P. MORTON. Modern Theatres and Cinemas. 1930.
STANLEY, DOUGLAS. The Science of Voice. 1929.
STEWART, GEORGE WALTER AND ROBERT BRUCE LINDSAY. Acoustics: a Text on Theory and Applications. 1930.
STOUGHTON, BRADLEY, AND ALLISON BUTTS. Engineering Metallurgy. Second edition. 1930.
TENNEY, FRANK F. Modern High Speed Ignition. 1930.
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WIEN, W., AND F. HARMS, editors. Handbuch der Experimentalphysik. Band 11, 3 Teil. 1931.
WOOD, ALEXANDER. Sound Waves and Their Uses. 1930.
World Almanac and Book of Facts for 1931.

BOOK REVIEWS.

A Manual of Celestial Photography: Principles and Practice for Those Interested in Photographing the Heavens. By Edward Skinner King, Sc.D., Phillips Professor of Astronomy, Harvard College Observatory. With a foreword by Harlow Shapley, Ph.D., LL.D., Director of the Harvard College Observatory. vi–177 pages, 39 figures, 12mo. Boston, Eastern Science Supply Co., 1931. Price, $3.00.

From the first attempts by Daguerre to photograph the Moon to such masterpieces of modern astronomical photography as Hubble's photographs of the Andromeda nebula through the 100-inch telescope at Mt. Wilson is a long step. It is a step that has taken nearly a century, but one that has meant a development which has increased our knowledge of the universe around us at a far greater rate than ever before. Photography has proven a useful tool in practically all branches of science, but it is doubtful whether its achievements in any other field have been as sensational as in the study of the heavens.

Both photography and astronomy have long been popular amateur hobbies, but the amateur who combines the two is somewhat of a rarity. Of course, there have been outstanding exceptions, such as the late Edward Emerson Barnard, who was first a photographer, then became interested in astronomy (and incidentally won enough prizes from the discovery of comets to pay for his house), then combined them and became one of the greatest of modern astronomical observers.

Perhaps the scarcity of adequate instruction for the amateur has been largely to blame. In various editions of George F. Chambers' "Astronomy," published soon after the middle of the last century, a chapter was devoted to the then novel topic of astronomical photography, and some instruction was given for the amateur who wanted to try it. Most modern works on general astronomy mention, at least, the importance of photography, but the reviewer knows of only one recent volume, except for the present one, to give the information the amateur needs in order successfully to turn his camera towards the stars. That little book, H. H. Waters' "Astronomical Photography," appeared in England in 1921, and it has been rather hard to obtain in this country. There has, therefore, been a real need for an American book on the subject, for the benefit of our growing group of amateur astronomers. No observatory is better equipped to provide such a book than the Harvard College Observatory, which has been the chief center of astronomical photography from the time of G. P. Bond's pioneer Moon photographs in 1850. And no Harvard astronomer is better equipped to write it than Dr. King, who has been photographing the heavens since 1887, and, as Dr. Shapley states in the preface, "has been directly responsible for the production of more celestial photographs than have been made by any other living person."

Here is just the information the amateur needs, the answers to the questions he would like to ask the expert. At the beginning are complete directions for making the simplest kind of an astronomical photograph, that of the polar star trails taken with a stationary camera. From this the author leads into the use of the telescope, the making of the necessary adjustments, methods of keeping the camera pointed accurately at the object as the earth turns, the kinds of plates to use and how they should be developed, printed and enlarged. The chapter on "The Amateur and his Telescope" gives full directions for making photographic equipment to use with a small telescope on a tripod mounting. Another gives a list of subjects to be photographed and directions telling how to take them best. The final chapters are devoted to such important supplementary topics as the action of light on the photographic plate, the photometry of stellar images and the measurement of their position.

It is to be hoped that this book will enjoy a wide popularity and that it may inspire many to take up this interesting hobby. Despite its successes, astronomical photography is still far from perfection. Many of the advances in the past have been due to the work of amateurs, so it offers not only a fascinating pastime, but the additional possibility of enabling one to contribute in a real way to the progress of science.

JAMES STOKLEY.

LEONARDO DA VINCI, THE ANATOMIST, 1452–1519. By J. Playfair McMurrich Professor of Anatomy University of Toronto. Carnegie Institution of Washington Publication No. 411. Williams & Wilkins Company, Baltimore, Copyright 1930, xx — 265 pages, price $6.00.

This treatise is devoted primarily to the work of Leonardo da Vinci as an anatomist, and his rôle as the forerunner of Vesalius who founded modern anatomy. From the time of Galen, at the end of the second century of the Christian era, the knowledge of anatomy was transmitted through the Arabs, the Moors, and the medieval universities. While dissections were made occasionally, they were of very little value; for the technic was superficial; spoilage of the cadaver necessitated haste; and certain rules of the Church interfered, thus, it was a sin to boil human bones. Leonardo made numerous dissections; he was familiar with methods for injection and imbedding and with the cutting of transverse sections. He also studied the heart beat. He possessed artistic ability and keen observation, discovered much that was new and prophetic of modern knowledge, and inaugurated a revolution in descriptive anatomy. Among the chapters, which number twenty-two, may be mentioned those devoted to possible sources of Leonardo's knowledge of anatomy, his fortunes and friends, his manuscripts and their reproductions, his methods, his canon of proportions, and his contributions to general anatomy and physiology, to the various systems (skeleton, muscles, circulatory, digestive, etc.), to embryology, to comparative anatomy, and to botany. The treatise contains ninety illustrations, and is provided with five pages of references, and a five-page glossary of Arabistic and other terms used by Leonardo. George Sarton of Harvard University has contributed a preface devoted to the position of Leonardo in the history of science. The book is excellent from all aspects, literary, scientific, and artistic.

JOSEPH S. HEPBURN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 356. Strength of Rectangular Flat Plates Under Edge Compression, by Louis Schuman and Goldie Back. 24 pages, illustrations, quarto. Washington, Government Printing Office, 1930. Price fifteen cents.

Flat rectangular plates of duralumin, stainless iron, Monel metal, and nickel were tested under loads applied at two opposite edges and acting in the plane of the plate. The edges parallel to the direction of loading were supported in V grooves. The plates were all 24 inches long and varied in width from 4 to 24 inches by steps of 4 inches, and in thickness from 0.015 to 0.095 inch by steps of approximately 0.015 inch. There were also a few 1, 2, 3, and 6 inch wide specimens. The loads were applied in the testing machine at the center of a bar which rested along the top of the plate. Load was applied until the plate failed to take any more load.

The tests show that the loads carried by the plates generally reached a maximum for the 8 or 12 inch width and that there was relatively small drop in load for the greater widths. This is explained by the fact that when the plate buckles, since the greatest deflection occurs at the center, its vertical chords will shorten more there than at the ends. In consequence there will be less load on the plate at the center and more toward the ends where it is better supported to resist bending and can continue to take load after buckling has occurred. In this way, the load carried by plates of a given thickness would tend to be constant for all plates wider than that at which the maximum load is reached.

Deflection and set measurements perpendicular to the plane of the plate were taken and the form of the buckle determined. The number of buckles was found to correspond in general to that predicted by the theory of buckling of a plate uniformly loaded at two opposite edges and simply supported at the edges.

The tests were made by the Bureau of Standards in coöperation with the Bureau of Aeronautics of the Navy Department, and submitted to the National Advisory Committee for Aeronautics for publication. The materials chosen were those suitable for aircraft construction. The data obtained will be of use in the design of floats, pontoons, wings, etc., of aircraft when the plating is subjected to pressure against the edges. It is desired to make this as light as possible, yet strong enough to take the required loads without permanent deformation.

Report No. 362. An Extended Theory of Thin Airfoils and its Application to the Biplane Problem, by Clark B. Millikan. 33 pages, illustrations, quarto. Washington, Government Printing Office, 1930. Price twenty cents.

The present paper gives a new treatment, due essentially to von Karman, of the problem of the thin airfoil. The standard formulæ for the angle of zero lift and zero moment are first developed and the analysis is then extended to give the effect of disturbing or interference velocities, corresponding to an arbitrary potential flow, which are superimposed on a normal rectilinear flow over the airfoil. An approximate method is presented for obtaining the velocities induced by a 2-dimensional airfoil at a point some distance away. In certain cases this method has considerable advantage over the simple "lifting line" procedure usually adopted. The interference effects for a 2-dimensional biplane are considered in the light of the previous analysis. The results of the earlier sections are then applied to the general problem of the interference effects for a 3-dimensional biplane, and formulæ and charts are given which permit the characteristics of the individual wings of an arbitrary biplane without sweepback or dihedral to be calculated. In the final section the conclusions drawn from the application of the theory to a considerable number of special cases are discussed, and curves are given illustrating certain of these conclusions and serving as examples to indicate the nature of the agreement between the theory and experiment.

Report No. 364. The Pressure Distribution Over the Wings and Tail Surfaces of a PW-9 Pursuit Airplane in Flight, by Richard V. Rhode. 103 pages, illustrations, quarto. Washington, Government Printing Office, 1930. Price sixty cents.

The investigation reported herein was conducted at Langley Field, Va., by the National Advisory Committee for Aeronautics at the request of the Army Air Corps to determine (1) the magnitude and distribution of aerodynamic loads over the wings and tail surfaces of a pursuit-type airplane in the maneuvers likely to impose critical loads on the various subassemblies of the airplane structure, (2) to study the phenomenon of center of pressure movement and normal force coefficient variation in accelerated flight, and (3) to measure the normal accelerations at the center of gravity, wing-tip, and tail, in order to determine the nature of the inertia forces acting simultaneously with the critical aerodynamic loads.

The investigation comprised simultaneous measurements of pressure at 120 stations distributed over the right upper wing, left lower wing, right horizontal tail surfaces, and complete vertical surfaces in one installation and the same number of points distributed over those portions of the wings in the slipstream and the left horizontal tail surfaces in another installation, during a series of level flight runs, pull-ups, rolls, spins, dives, and inverted flight maneuvers. Measured also were the accelerations mentioned above, angular velocities, air speed, and control positions simulatneously with the pressures.

The results obtained throw light on a number of important questions involving structural design. Some of the more interesting results have been discussed in some detail, but in general the report is for the purpose of making this collection of airplane-load data obtained in flight available to those interested in airplane structures.

Report No. 371. Present Status of Aircraft Instruments, by Subcommittee on Air Navigation Instruments, N. A. C. A. 26 pages, illustrations, quarto. Washington, Government Printing Office, 1930. Price fifteen cents.

The present state of development of aircraft instruments is summarized with emphasis on the present trend of development. The report includes sections on speed instruments, altitude instruments, navigation instruments, power plant instruments, oxygen instruments, instruments for aerial photography, fog flying instruments, general problems, and summary of instrument and research problems.

The relative utility of the various types of instruments available for any one definite purpose is discussed in so far as reliable data are available. The research problems considered include both those of special interest to instrument engineers and to operators of aircraft. References are given to the more recent fundamental papers on the subject.

R.

THE DYNAMIC UNIVERSE. By James Mackaye, Dartmouth College. X–308 pages, 8vo. New York, Charles Scribner's Sons, 1931. Price $3.50.

As with most articles for popular consumption, this book, bound in plain blue with gilt title, has been provided with a relatively attractive jacket. Outside its obvious purpose, that of making the casual observer look twice (and in this it seems quite successful), the jacket provides space for a biographical note on the author and a statement as to what the book is all about.

The author, James Mackaye, is avowedly a philosopher who has had a background of chemical and physical research on a variety of engineering problems. At present, a lecturer ar Dartmouth College, Professor Mackaye has undertaken the task of thoroughly sifting the so-called theory of relativity through a fine mesh screen of perception and discrimination. Whether he has successfully separated the good from the bad, the "so" from the "not so," fact from presumption, physics from metaphysics, time alone will decide.

It is pointed out in the introduction that the theory of relativity is closely associated with four critical experiments:

1. The Fizeau experiment involving a comparison of the velocity of light in stationary and moving water.

2. The Airy experiment, which consisted in comparing the aberrational angle of a star, using first a telescope filled with air, and then one filled with water.

3. The Michelson-Morley experiment for comparing the velocity of light in two directions at right angles to each other.

4. The Kaufmann-Bucherer experiment which consisted in comparing the deviations at varying velocities of cathode rays from a straight path as caused by a magnetic field.

Apparently the author has no quarrel with the present relativity equations which fit the facts very logically. However, he, like many others, does take issue with the cosmic structure postulated by the ardent supporters of the relativity theory.

As a substitute, Professor Mackaye introduces the radiation theory, pointing out that it also will satisfy the various relativity equations. In the light of this theory the author undertakes to explain the cause of gravitation, matter, increase of interial mass with motion, the Lorentz contraction, potential energy, inertia, impenetrability and light. Also, the radiation theory may be able to throw some light on such questions as to whether gravitation is due to longitudinal radiation; what is the cause of light; what becomes of star-light and gravitation; are conditions favoring the destruction and creation of matter present in the universe? Is the universe reversible?

Following an exposition of the radiation theory, the assumptions of the relativity theory are questioned by the author. Quotations from Einstein, Bridgman and Eddington are submitted and the inconsistencies and illogicalities pointed out.

Thus it may be that radiation is the cause of all physical phenomena, that there is an ether, that, as the "jacket" says: "There is reason to believe this book will cause a sensation in academic and scientific circles. The author is to be commended for his penetrating analysis of the relativity postulates and his attempt to crystallize from fact and thought the existence of a dynamic universe whose behavior is described by the radiation theory.

T. K. CLEVELAND.

PUBLICATIONS RECEIVED.

Numerical Mathematical Analysis, by James B. Scarborough, Ph.D. 416 pages, tables, 8vo. Baltimore, The Johns Hopkins Press, 1930. Price $5.50.

Flights from Chaos, A Survey of Material Systems from Atoms to Galaxies, by Harlow Shapley, 168 pages, tables, illustrations, 8vo. New York, McGraw-Hill Book Company, Inc., 1930. Price $2.50.

La Telephonie, par Robert Dreyfus. 199 pages, illustrations, 16mo. Paris, Librairie Armand Colin, 1931. Price 10 fr. 50.

Mecanique des Fluides, par M. Henri Villat, Cours de l'Ecole Nationale Superieure d'Aeronautique, 175 pages, illustrations, 8vo. Paris, Gauthier-Villars et Cie, 1930. Price 50 fr.

Lecons sur le Calcul Vectoriel, par T. A. Ramos. 119 pages, 8vo. Paris, Librairie Scientifique Albert Blanchard, 1930. Price 25 fr.

Le Premier Principe Rien N'Est Abritraire, la Mecanique fondee sur une theorie des chocs durs, par Zareh Nubar, 407 pages, illustrations, 8vo. Paris, Librairie Scientifique Albert Blanchard, 1930. Price 50 fr.

Essentials of Organic and Biological Chemistry, by E. Wertheim, Ph.D. 175 pages, tables, illustrations, 8vo. Easton, The Chemical Publishing Co., Inc., 1931.

A Textbook of Practical Physical Chemistry, by K. Fajans, and J. Wust, translated from the German by Bryan Topley with a preface by F. G. Donnan, LL.D., F.R.S., 233 pages, illustrations, 8vo. New York, E. P. Dutton and Company, Inc., n.d. Price $4.95.

Physics, A Textbook for Colleges, by Oscar M. Stewart, revised edition, 770 pages, tables, illustrations, 8vo. Boston, Ginn and Company, n.d. Price $4.00

Bell Telephone Laboratories, Monographs: No. B–522, An Efficient Loud Speaker at the Higher Audible Frequencies, by L. G. Bostwick, 8 pages, illustrations, 8vo. B–524, The Trend in Design of Telephone Transmitters and Receivers, by W. H. Martin and W. F. Davidson, 6 pages, 8vo. B–529, Transmission Characteristics of Open-Wire Telephone Lines, by E. I. Green, 30 pages, illustrations, tables, 8vo. B–530, Transients in Parallel Grounded Circuits, by Liss C. Peterson, 10 pages, illustrations, 8vo. B–531, Impedance Correction of Wave Filters, by E. B. Payne, 24 pages, illustrations, 8vo. B–532, A Method of Impedance Correction, by H. W. Bode, 42 pages, tables, illustrations, 8vo. B–533, Microphonic Action in Telephone Transmitters, by Frederick S. Goucher, 7 pages, illustrations, 8vo.

Monaco, International Hydrographic Bureau, Year Book, 1931, 158 pages, 16mo. Monaco, n.d.

National Advisory Committee for Aeronautics. Technical Notes, No. 361, The Effect of Small Variations in Profile of Airfoils, by Kenneth E. Ward, Langley Memorial Aeronautical Laboratory, 9 pages, tables, diagrams, quarto, Washington, Committee, 1931. No. 362, Lift and Drag Characteristics of a Cabin Monoplane Determined in Flight, by F. L. Thompson and P. H. Keister, Langley Memorial Aeronautical Laboratory, 11 pages, tables, diagrams, plates, quarto, Washington, Committee, 1931. No. 363, The Behavior of Conventional Airplanes in Situations Thought to Lead to Most Crashes, by Fred E. Weick, Langley Memorial Aeronautical Laboratory, 13 pages, plates, diagrams, tables, quarto, Washington, Committee, 1931. No. 364, Tests in the Variable Density Wind Tunnel to Investigate the Effects of Scale and Turbulence on Airfoil Characteristics, by John Stack, Langley Memorial Aeronautical Laboratory, 15 pages, diagrams, quarto, Washington, Committee, 1931.

CURRENT TOPICS.

General Survey of the Effects of Pressure on the Properties of Matter. P. W. BRIDGMAN. (*Proc. Phys. Soc.*, London, Vol. 41, Pt. 4.) Prof. P. W. Bridgman, Hollis Professor of Mathematics and Natural Philosophy in Harvard University, delivered the fourteenth Guthrie lecture before the Physical Society and in it gave an account of his long and important investigations on the effects of pressure upon the properties of matter. The point was emphasized that the pressures employed were of the order of tens of thousands of kilograms per sq. cm. So high a pressure is necessary for the production of notable effects since the atomic or molecular forces in common solids and liquids are of this magnitude. In the apparatus a special type of packing was used that prevented the leaking of the liquid by which the high hydrostatic pressure was applied. Thus the pressure employed had its upper limit set by strength of the containing vessels. Pressures reaching beyond 20,000 kg./cm.^{2} were produced and measured to 0.1 per cent. However, to spare the apparatus, 12,000 kg. was usually not exceeded.

Diminution of Volume.—"The change of volume of any truly homogeneous substance free from internal strains, is entirely reversible with pressure; no permanent change of volume has ever been observed up to a pressure at least as high as 25,000 kg. Contrary statements sometimes found in the literature are to be explained either by flaws in the material or else by failure of the pressure to be truly hydrostatic, as when pressure is transmitted by an oil which freezes under pressure, thus producing permanent changes of figure in the material."

Liquids are generally more compressible than solids. After a pressure a few thousand kg./cm.^{2} in excess of the critical pressure has been passed gases, called permanent, and liquids closely resemble each other in compressibility. Long ago Amagat found that air at 3000 kg./cm.^{2} has the density of water. The main difficulty in studying the compressibility of gases through a great range of pressures lies in the enormous ratio of the initial to the final volume. For perfect gases the product of pressure and volume, temperature being constant, is supposed to be constant. This is far from true at high pressures. Bridgman, extending the work of Amagat, found that for nitrogen, hydrogen and helium the product of pressure and volume goes on increasing linearly up to 13,000 or more kg./cm.^{2}

Helium acts most like a perfect gas but at 15,000 kg./cm.^{2} its volume is 6 times as great as a perfect gas should possess. For nitrogen the corresponding ratio is 16. Curves were displayed showing the instantaneous compressibility of the three gases above named and of carbon disulphide and water, that is, the fraction of the volume at any pressure by which the addition of a unit of pressure further reduces the volume, the temperature of each substance remaining constant throughout. "At the lower pressures, in the neighborhood of 3000 kg., the compressibility of the gases is several fold greater than that of liquids, but at the highest pressure, 15,000 kg., the compressibility of all is nearly the same." From an examination of the changes in the compressibility of certain gases the author concludes: "At comparatively low pressures, the decrease in the volume of a gas has its origin in a decrease of the empty space between the atoms or molecules, but as the molecules are pushed into closer contact, this effect becomes exhausted, and at high pressures this contribution to compressibility disappears. But there is another factor in the compression, namely, the actual loss of volume of the molecules themselves, and this evidently may persist at pressures where the initial effect no longer exists. This behaviour, so definitely shown by these gases, is typical of the behaviour of all substances at high pressures. Beyond the first few thousand kilograms, the major part of the loss of volume is provided by the atoms or molecules themselves, and those substances with the most complicated or the most loosely constructed molecules have the greatest compressibility at high pressures, although at low pressures the behaviour may be the reverse."

The volume changes caused in liquids by pressure are much more nearly equal at high pressures than at low. Of 14 common liquids water turned out to be the most compressible. "At 12,000 kg. the compressibility of 14 organic liquids varies from 1/14 to 1/20 part of the initial compressibility; half of the drop to the final value is accomplished in the first thousand kilograms, and at 6000 kilograms the drop is 95 per cent. completed." The effect of pressure on volume for different pressures was measured, and effect of pressure on thermal expansion was deduced therefrom Thermal expansion grows less with increasing pressure but it does not decrease to the same extent as the compressibility and, in addition, the coefficients of thermal expansion of 14 liquids, water not included, lie nearer together under 12,000 kg. than do the compressibilities. "At atmospheric pressure the thermal expansion of all liquids increases with increasing temperature, but in the neighborhood of 3000 kg. there is a reversal, and at higher pressures thermal expansion is greater at lower temperatures than at higher."

Solids are less compressible than the liquids they form on melting. This is true no matter whether the solid expands or contracts on melting. Solids, moreover, change less in compressibility with increasing pressure than do liquids. It would seem that the major part of the compressibility of a solid depends on compression of its atoms or molecules. Cæsium has the greatest compressibility of all the metallic elements, and possesses a complicated atom. This is in accord with the fact that its compressibility at high pressures is greater than that of ether, the most compressible organic liquid.

The effect of pressure on the compressibility of crystals in different directions was examined. "The linear compressibility may vary much more with direction than might be expected from the difference of atomic spacing in different directions. Thus the linear compressibility of Zn parallel to the hexagonal axis is seven times as great as at right angles, whereas the ratio of the atomic spacing in the two directions is only 7 per cent. different from that for spherical atoms in normal hexagonal piling, and in fact the spacing is compressed along the axis, while the compressibility is greater along the axis. The behaviour of tellurium is highly unusual, in that there is negative compressibility along the trigonal axis; that is, when exposed to hydrostatic pressure a crystal of Te expands in the direction of the axis."

Change of State Produced by Pressure.—From analogy with the conditions governing the passage from the liquid to the gaseous state it has been held that there is likewise a critical point between liquid and solid. Tammann maintained that there is a maximum melting temperature such that above it a substance can exist only in the liquid state no matter how great a pressure be applied. Experiments on nearly 40 substances up to 12,000 kg. and on water up to 21,000 kg. fail to substantiate either of these suppositions.

Water under suitable conditions of temperarature and pressure can exist in five solid forms of which ordinary ice is the only one lighter than water. Tammann discovered two of these. Ammonium nitrate also exists in 5 solid modifications and perhaps in a sixth at a lower temperature than the rest. Camphor has 6 modifications.

Effect of Pressure on Electrical Resistance.—"Out of 48 pure metals which have been measured, the resistance of 39 decreases under hydrostatic pressure by amounts varying with the character of the metal from 1 per cent. under 12,000 kg. for Co to 73 per cent. for K. The effect of a given increment of pressure becomes less at high pressures. Six or seven of the 48 metals, Li, Ca, Sr, Sb, Bi, the low-pressure modification of Ce, and perhaps Ti, increase in resistance under pressure." Some metals pass through a minimum of electrical resistance as the pressure rises. Such are Cs, Ba and Rb.

Effect of Pressure on Thermal Conductivity.—"The effect of pressure up to 12,000 kg. has been measured on the thermal conductivity of 11 metals. The measurement is much more difficult to make than of resistance, and the results are not so accurate. Of the 11 metals, the thermal conductivity of 5 increases under pressure and that of 6 decreases." The effect of pressure on the thermal conductivity of 15 liquids was measured up to 15,000 kg. "The effect is to increase thermal conductivity by fairly large amounts, the factor of increase varying from 1.5 for water, the least compressible of the substances measured, to 2.74 for normal pentane."

Effect of Pressure on Viscosity.—This effect was determined for 43 liquids. Viscosity for all except water increases with the addition of pressure. The effect of pressure on viscosity and its variation from substance to substance are larger than for any other property of matter. "The factor of variation under 12.000 kg. is 1.33 for mercury and 10^7 for eugenol ($C_3H_5 \cdot C_6H_3 \cdot OH \cdot OCH_3$). Viscosity increases geometrically with pressure. There is a very close correlation between the magnitude of the pressure effect and the complexity of molecular structure, the pressure coefficient being least for monatomic Hg and greatest for complicated organic substances like eugenol. There would seem to be little question that a large part of the viscosity of a liquid is purely mechanical in origin, arising from the jamming together or interlocking of the molecules.

G. F. S.

Frictional Electricity. P. E. SHAW. (*Phil. Mag.*, April, 1930.) In view of the great progress made in electrical knowledge in general it is surprising that so little is known about frictional electricity. However, during the last fifteen years some progress has been made. Some of these results are now presented. It is not necessary to pass a charged body through a flame in order to discharge it. The ionized gases near the flame are quite effective. If a glass rod that has been producing positive electricity when rubbed with silk is put for a very short time in a flame and then rubbed as before with silk it becomes negatively electrified and the friction is greater than before. Continued rubbing will finally reduce the friction and bring back the positive electrification. This reversal of charge can be accomplished by using ordinary silk, flannel or felt, but not if they have been freed from fats and waxes by benzine or chloroform. If on the cleaned fabric some solid organic compound of low melting point be placed (fatty, bibasic, or aromatic acids, esters or ketones) the reversal takes place. In the ordinary experiment of rubbing glass it is a layer of organic substance that is rubbed and becomes positively charged. Upon passing the glass through a flame this layer is removed.

Faraday noticed that seemingly identical solids became charged when they were rubbed together. Two identical pieces of ebonite, taken from the same rod, heated in boiling water, dried and cooled, show this effect. Lay one piece *A* across the other *B* and stroke *B* with *A*. *B* becomes positive and *A* negative. If the rods are interchanged the rubbing rod again becomes negative. Long continued rubbing causes the charges to lessen, to disappear, and at last to reverse. The formation of electricity depends on a difference in strain on the two rods. In a stroke the friction acts on the same area of one rod but on the other is on a constantly changing area. Thus the rods are no longer identical. The reversal depends on the annealing effect of the generated heat.

"Let two rods of ebonite or other good insulator be struck together violently with a glancing blow so as to meet in oblique, not normal impact. If the two rods be then together brought near a gold-leaf electroscope there will generally be found on them a net *negative* charge of considerable amount. Faraday's law states that the charges on the two surfaces produced by rubbing are equal and opposite, *i.e.*, the net charge is nil." This equality actually exists in cases of rubbing. It may be that one or both of the rods have lost some positive electricity to the air. When sand is blown through a sand-tube and metal filings through a tube of the same metal, the blown material, tube and air all are found to be charged. The impact here is oblique. Here is seen an explanation of electrical sand-storms and snow-storms.

There are three kinds of films on surfaces that affect results in frictional electricity. 1. absorbed films of water especially on glass. These go to produce negative electricity. 2. alkaline films. These too act negatively, producing when rubbed negative (OH) ions. 3. acid films which act positively, giving positive H ions.

Though solid surfaces are still far less understood than are surfaces of liquid yet "much light has been shed on their composition by many different lines of reasoning, notably: the theory of the lattice electrical structure of crystals; the Debye theory of the dipole nature of dielectric molecules; the double electric layer theory of Helmholtz; Hardy's theory of boundary lubrication; and the Langmuir-Adam work on the monomolecular solid films on water."

G. F. S.

Vertical Electrical Currents below Thunderstorms and Showers. T. W. WORMELL. (*Proc. Roy. Soc.*, A 806.) A discharge point was supported on a pole 12.3 meters high in the center of a field bordered by high trees. The nearest tree was about 70 m. from the point. The point was joined electrically to the ground through a specially designed micro-voltameter that gave the amounts of electricity that had traversed the instrument correct to about .5 millicoulomb. The quantity of positive and of negative electricity discharged from the point was calculated from the volume of gas set free at the two electrodes. A table presents the results obtained for 75 days in 1927 and for 53 days in 1928. The largest discharge of positive electricity from the point took place on Feb. 24, 1927, a day with a heavy shower succeeded by steady rain for hours, and amounted in all to 28.5 millicoulombs. On the same day 3.3 millicoulombs of negative electricity was discharged by the point. On Dec. 26, 1927 25.8 units of negative electricity escaped from the point and 8.8 of positive. For all the days of observation in the two years the total positive discharge from the point amounted to .52 coulomb and the corresponding negative amount was .25 coulomb. The consistency of the excess of positive over negative is brought out by a comparison of the discharges of the two kinds of electricity for the eight quarter-years covered by the observations. In only one of these eight is the negative discharge the larger. Generally there is no discharge in fine weather but occasionally with a cloudless sky negative electricity escapes. When there is precipitation net discharge of positive electricity is about three times as common as of negative.

To follow the changes in the escape of electricity from the point "the current itself could also be observed by allowing it to charge up a condenser until the potential difference was sufficient to cause a spark to pass across a small gap, the process of the charging and sudden discharge of the condenser being recorded photographically by means of the movement of the meniscus of a special type of capillary electrometer." In addition the intensity of the electric field near the ground was measured. Thus the course of the electric phenomena occurring during a thunderstorm could be closely followed. Potential gradient is counted positive when it is directed toward the earth. For a storm on March 27, 1927, at 3:10 p.m. the potential gradient was + 200 volts per meter. The positive gradient kept increasing as a cloud approached and at 3:15 it was 600 volts/m. The potential stayed positive until 3:33 when it reversed sign. At that time there set in a strong discharge of positive electricity from the point. The negative gradient and the strong discharge kept up till 3:55, heavy rain falling meanwhile. After this there was a negative discharge along with a reversal of field. As the clouds receded the gradient assumed its normal value for fine weather, at 4:13, 4:15 and 4:24 having values of + 600, + 400 and

+ 200 volts/m. respectively. In other storms much more complicated electrical variations were recorded.

The electrical charge of the earth may change by four processes, 1. by streams of ions in the air bringing charges to the earth in fine weather, 2. by precipitated water or ice conveying charges to the earth. 3. by charges brought by lightning discharges and 4. by the discharge of electricity by points connected to the earth. The author endeavors to estimate the quantity of electricity brought to one sq. km. of the earth's surface in a year by each of these actions. He fixes the quantities as follows: "Fine weather current + 60 coulombs, Precipitation + 20, Lightning discharges − 20, Currents carried by point discharges − 100. The estimates are admittedly very rough ones; it would appear, however, to be quite possible that the four processes balance one another approximately, or even that in this locality (Cambridge, England) the earth on the whole gains a negative charge."

G. F. S.

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Walton Clark
Cyrus H. K. Curtis
Charles Day
Samuel S. Fels
Arthur W. Goodspeed
Clarence A. Hall
George A. Hoadley
A. Atwater Kent
L. H. Kinnard
Elisha Lee
Robert W. Lesley
Lionel F. Levy
Malcolm Lloyd, Jr.
Robert McLean
Charles Penrose
James S. Rogers
George D. Rosengarten
E. H. Sanborn
Haseltine Smith
Samuel T. Wagner